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# A Preliminary Assessment of the Environmental Conditions of Two Abandoned Uranium Mill Tailings Sites in Saskatchewan

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# A Preliminary Assessment of the Environmental Conditions of two Abandoned Uranium Mill Tailings Sites in Saskatchewan.

submitted to:

Saskatchewan Environment
and Environment Canada

by:

M. Kalin
Institute for Environmental Studies
University of Toronto
Toronto, Ontario.

In fulfillment of Contract #31 (80-81)
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## REVIEW NOTICE

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TABLE OF CONTENTS


| | | |
|---|---|---|
| SUMMARY AND RECOMMENDATIONS | | vii |
| | Gunnar Mill Tailings Sites | vii |
| | Lorado Tailings and Nero Lake | x |
| INTRODUCTION | | 1 |
| APPROACH AND OBJECTIVE OF PHASE I | | 3 |
| | 1. Gunnar tailings in Mudford Lake. | 3 |
| | 2. Lorado tailings in Nero Lake. | 4 |
| STUDY LOCATION AND BRIEF HISTORY OF THE SITES | | 5 |
| METHODS USED IN BOTH LOCATIONS | | 7 |
| 1. | GUNNAR MILL TAILINGS SITES - RESULTS | 9 |
| 1. | Surface Descriptions | 9 |
| 1.1.1 | Windblown tailings | 9 |
| 1.1.2 | Grass covered tailings | 11 |
| 1.1.3 | One-hundred percent vegetation cover | 15 |
| 1.1.4 | Surface water and moist sections | 16 |
| 1.2 | Tailings Characteristics | 19 |
| 1.2.1 | Physical and chemical determinations | 19 |
| 1.2.2 | Concentrations of elements | 20 |
| 1.2.3 | Vegetation uptake of elements | 29 |
| 1.3 | Gunnar Discussion | 40 |
| 2. | LORADO - NERO LAKE - BEAVERLODGE BAY - RESULTS | 43 |
| 2.1 | Description and Field Observations | 43 |
| 2.1.1 | Tailings surfaces of Lorado sites | 43 |
| 2.1.2 | Nero Lake | 43 |
| 2.1.3 | Beaverlodge Bay | 46 |
| 2.2 | Chemical Characteristics | 48 |
| 2.2.1 | Tailings - sediments | 49 |
| 2.2.2 | Water in Nero Lake - Beaverlodge Bay | 54 |

| | | |
|---|---|---|
| 2.3 | The moss in Nero Lake | 61 |
| 2.3.1 | Moss growth and chemical analysis | 61 |
| 2.3.2 | Moss aquaria and experiments | 67 |
| 2.4 | Lorado - Nero Lake - Beaverlodge Bay - Discussion | 69 |
| PLATES | | 73 |
| REFERENCES | | 97 |
| ACKNOWLEDGEMENTS | | 99 |
| APPENDICES: | | 100 |
| | Appendix A - Terms of References | 100 |
| | Appendix B - Detailed Methods | 102 |
| | Appendix C - Radionuclides Ra 226 and Pb 210 Concentrations. | 121 |

## LIST OF TABLES


| | | |
|---|---|---|
| TABLE 1. | Plants collected from Transect I - III on Gunnar and associated sites. | 14 |
| TABLE 2. | Gunnar Mill and Beaverlodge Bay water samples | 17 |
| TABLE 3. | Water characteristics of Gunnar and surroundings determined in mg/l, not included in the maps. | 18 |
| TABLE 4. | Gunner tailings and soils characteristics | 20 |
| TABLE 5a. | Distribution of some elements and concentrations factors in H. jubatum growing on Gunnar tailings and Ace Creek tailings (Eldorado) in µg/g. | 35 |
| TABLE 5b. | Grasses dominant on Gunnar Main and Gunnar Central tailings Element conc. µg/g. | 37 |
| TABLE 5c. | Concentrations of Cu, Ni, Pb and Co in ppm (dry weight) in T. latifolia parts. | 39 |
| TABLE 6. | Water on the berm between Nero Lake and Beaverlodge Bay. | 44 |
| TABLE 7. | Zone in Beaverlodge Bay influenced by Nero Lake discharge. | 47 |
| TABLE 8. | Water characteristics of Beaverlodge Bay. | 47 |
| TABLE 9. | Tailings characteristics Lorado - Nero Lake - Beaverlodge Bay. | 51 |
| TABLE 10. | Heavy metals in materials associated with Nero Lake. | 55 |

| | | |
|---|---|---|
| TABLE 11. | Concentrations of elements in materials associated with Nero Lake. | 56 |
| TABLE 12. | Water stratification of Nero Lake in August 1980. | 58 |
| TABLE 13. | Water characteristics and heavy metal concentrations in Nero Lake. | 59 |
| TABLE 14. | Comparison of water determinations from 1976 to 1980 in Nero Lake and Beaverlodge Bay. | 62 |
| TABLE 15. | Element concentrations in *L. riparium* in Nero Lake and control sites in µg/g dry weight. | 64 |
| TABLE 16. | Elemental ratios of *L. riparium* over substrates in Nero Lake. | 65 |
| TABLE 17. | Control on analysis and digestion procedure. | 107 |
| TABLE 18. | Atomic absorption detection limits and errors. | 108 |
| TABLE 19. | Standard material determined by Neutron activation analysis during U.C. sample determinations. | 110 |
| TABLE 20. | Neutron activation detection limits and errors. | 112 |

## LIST OF MAPS


| | | |
|---|---|---|
| MAP 1: | Location of Gunnar and Nero Lake - Beaverlodge Bay | 6 |
| MAP 2: | Estimates of Surface Type Distribution | 10 |
| MAP 3: | Location of Tailings, Soil, Vegetation Samples and Transects | 12 |
| MAP 4: | Tailings/soil ranges in percent Al | 23 |
| MAP 5: | Tailings/soil ranges in percent Ca | 24 |
| MAP 6: | Tailings/soil ranges in µg/g Cu | 25 |
| MAP 7: | Tailings/soil ranges in µg/g Pb | 26 |
| MAP 8: | Tailings/soil ranges in µg/g U | 27 |
| MAP 9: | Tailings/soil ranges in µg/g Co | 30 |
| MAP 10: | Tailings/soil ranges in percent Mg | 31 |
| MAP 11: | Tailings/soil ranges in µg/g Mn | 32 |
| MAP 12: | Tailings/soil ranges in µg/g Ni | 33 |
| MAP 13: | Tailings/soil ranges in µg/g V | 34 |
| MAP 14: | Location of water and moss samples | 45 |
| MAP 15: | Location of tailings and sediments samples. | 50 |

## LIST OF FIGURES


| | | |
|---|---|---|
| FIGURE 1. | Heavy metal concentrations in substrates: Lorado tailings - Nero Lake - Beaverlodge Bay. | 53 |
| FIGURE 2. | Heavy metal concentrations in water on Lorado tailings, in Nero Lake, in Beaverlodge Bay and control waters. | 60 |
| FIGURE 3. | pH Monitoring Results - solutions without moss. | 118 |

## SUMMARY AND RECOMMENDATIONS

### Gunnar Mill Tailings Sites

The total area of the three exposed tailings surfaces from Gunnar Mill cover an estimated 22 ha. The areas are referred to as Gunnar Main, Gunnar Central and Langley Bay.

The Gunnar Main tailings pond is approximately 16 ha and has been invaded by two types of vegetation communities, which stabilize, to some degree, approximately two-thirds of the tailings surface. The remainder of the tailings surface consists of windblown tailings and requires amelioration (Map 2).

Windblown tailings are covering the tree trunks up to 1 m in depth adjacent to the tailings pond edge. Exposure and the loose texture of the tailings, in addition to low moisture content appear intuitively as critical restricting factors for vegetation in this section of the tailings pond.

One of the vegetation covers, on Gunnar Main, is dominated by grasses some of which are *Hordeum jubatum* and *Festuca rubra*. The grasses appear to inhabit mainly compacted dry tailings.

The second vegetation cover is dense and completely stabilizes the surface, consisting of wetland species dominated by sedges and rushes, some of which are identified as Juncus balticus, Carex rostrata and Carex aquatilis. Typha latifolia colonies surround some small ponds but do not appear as vigorous in growth as the other wetland vegetation.

The Gunnar Central tailings are also stablized by a grass cover which is dominated by Calamagrostis inexpansa and some Carex aquatilis. Some trees and shrubs have invaded the tailings on the edges. On Langley Bay the dominant grass was identified as Deschampsia fleuxuosa, a grass which differs from the other two locations.

Chemical characteristics were analysed with the emphasis on Gunnar Main tailings. The moisture content was determined as 10-20% and the pH as 6.5-7.5. Since the abandonment of the tailings in 1964, little organic material has accumulated (L.O.I. 2-4%). All tailings were analysed for Cu, Ni, Co, Pb, U, Al, Ca, Mn, Mg, V and were determined as present in normal soil concentrations (Bowen 1966; Jonasson 1973) with the exception of lead and uranium (Maps 4 to 13, Appendix II). Since the nature of the tailings is alkaline, these two potentially toxic elements are not likely available to vegetation. The vegetation was analysed for elemental uptake. Three different grass species indicated no accumulation (Table 5a-c). In summary, the chemical nature of the Gunnar Mill tailings investigated in this study does not indicate a chemical toxicological concern. Lead and uranium however, may require specific metal tolerances in the existing vegetation.

Surface water associated with Gunnar Mill tailings was not severely contaminated, based on the parameters determined. The water was neutral to alkaline, with relatively high conductivity (2000-7000 µmhos/cm). These ranges are common of seepage water and water in ponds on top of the tailings (Table 3).

To ameliorate the windblown area of Gunnar Main, it is recommended to promote natural vegetation, which has already partly invaded the tailings surface, and thereby demonstrated tolerance to some conditions encountered on the tailings.

Vegetation tolerant to these conditions, for example, the noted elevations of lead and uranium, could apparently provide long-term stabilisation of the windblown area. These recommendations are made, particularly as the location of the Gunnar tailings is such that continued maintenance of the vegetation may be very costly. The detailed recommendations given below in point form consider as well the availability of material on the site in view of the economics involved with other amelioration measures such as practiced in more easily accessible sites.

The recommendations for the next phase of the study are:

1. Investigate in detail composition and character of the two observed plant communities: grass cover and wetland species association. It is only then possible to attempt to assist these communities in further stabilisation of the tailings.

2. Attempt to transplant Hordeum jubatum L. and Festuca rubra hummocks to the windblown area of the tailings pond. A water supply and windshelters are required. It is recommended to utilize dead trees as shelters and water of the open pit as a water supply. This water is possibly rich in nutrients, as the fish processing plant is disposing fish wastes in the pit.

3. Carry out further analysis of tailings with emphasis on radionuclides and some other heavy metals not determined in this survey. Collect the samples with particular emphasis on the surfaces types, described in Phase I of the study.

These three aspects, if carried out, will lead to a more comprehensive understanding of the existing flora; determine the success of establishing grass hummocks in the windblown area; and delineate more thoroughly chemical characteristics of the tailings and associated potential problems.

Lorado tailings and Nero Lake

The tailings from the Lorado Mill were discharged untreated at pH 1.7-2 into a small lake at the west end of Nero Lake. The lake overflowed in the first year of operation and 335,000 short tons of tailings were deposited in Nero Lake. Nero Lake became acidic, and is at present consistently at pH 3.5 throughout the entire lake. Nero Lake drains into a small inlet (of Hanson Bay), referred to as Beaverlodge Bay in this report (Map 14). The surface water plume in August 1980 was 12 m wide and 15-20 m long.

This acidic discharge may pose some water quality problems to Beaverlodge Bay in the long-term. The water in Nero Lake has a conductivity of 200 µmhos/cm in contrast to the adjacent Beaverlodge Bay, where conductivity is around 200 µmhos/cm and the pH around 7.5. Cobalt and nickel are elevated in Nero Lake. Copper and lead are considerably less elevated when the concentrations are compared to Beaverlodge Bay and the control area (Fig. 2).

(Page 61). Water characteristics have not changed over the last four years as indicated by a comparision of data from previous years (Table 3, page 18).

Concentrations of cobalt, nickel and copper in tailings and in sediments from Nero Lake and Beaverlodge Lake were determined. The ranges of concentrations were found to be comparable in Nero Lake and Beaverlodge Bay for cobalt, nickel and copper. Lead in tailings from Nero Lake is elevated above background soil values (Bowen 1966) and sediment concentrations in Beaverlodge Bay. The lead values determined in tailings are double the recommended concentrations of 56 ppm in soils (MOE 1976).

The moss Leptodyctium riparium (Hedw.) Warnst was identified on the shore and on the bottom of Nero Lake. The moss survived in laboratory tanks for five months, and some of it still remains and is growing. Preliminary experiments resulted in a practicable method to determine growth conditions for L. riparium.

The analysis of the moss indicates that element concentrations are approaching those of the tailings. However, the elemental concentrations vary between the samples, but it appears that some metals are concentrated. This is especially the case if uptake by the moss is considered in relationship to the water.

The Nero Lake and the Lorado Mill tailings present a problematic situation with respect to rehabilitation of the site. Effectively no suitable natural vegetation has invaded the Lorado tailings in the past decades. Clearly

the major cause is the sulphur content (5%), and elevated lead levels do not help the situation.

Chemical stabilization with lime or limestone, followed by revegetation similar to that of Elliot Lake tailings, appears to be a good approach which has shown to be successful (Murray, 1978). Given the conditions of this particular site, extreme caution needs to be taken that run-off from the treated surface would not affect the complex chemical balance at present existing in Nero Lake. As this may not be possible, until a better understanding of Nero Lake is obtained, chemical stabilization is not recommended.

As a viable and economic approach to rehabilitation, consideration could be given to existing Typha latifolia stands. The aim would be to promote their growth in such a way as to cover the entire surface of the exposed tailings. The surviving colonies on the edges of the tailings have to be investigated in detail.

Consideration could be given to a rehabilitation scheme that would cover the exposed tailings with top soil or other available material (e.g. gravel). On such a cover, vegetation could then be established. However, any rehabilitation of the exposed tailings should be carried out in such a way that the water in Nero Lake is not affected.

In fact, it is strongly recommended that the conditions which occurred in Nero Lake should be better understood before any action is taken on the exposed tailings. The likelihood of adverse effects on

Beaverlodge Bay is considerably high - should drastic changes take place in Nero Lake, due to amelioration on the exposed tailings. This is emphasised by the complex and apparently fragile balance between Nero Lake and Beaverlodge Bay.

Further, the role of L. riparium covering the bottom of the lake has to be clarified. It is recommended that a literature search focusing on the findings of this survey be conducted. Based on the results of a thorough literature review, sound recommendations can be made for field and laboratory experiments. These experiments should aim to delineate the growth conditions of L. riparium in Nero Lake.

In addition to the clarification of the role of L. riparium, it is recommended to determine some dynamic aspects of Nero Lake water chemistry. As the existence of selective binding of lead and copper is suggested from this survey and an organic transport mechanism for uranium, the need to determine organic substance in Nero Lake is evident. The source and control of pH in Nero Lake and the potential existence of humic/fulvic substances need to be determined to facilitate a rehabilitation of the entire system. If these recommendations are disregarded, the possibility exists that the present system is destabilized by amelioration efforts and adverse effects on Beaverlodge Bay are possible.

## INTRODUCTION

The uranium mining and milling industry is rapidly expanding in Saskatchewan, and it is expected that, in spite of the recent weakness in uranium demand in the world, this trend will continue well into the future. The approximate projections indicate that between 1980 and the year 2000, Saskatchewan may produce a total of 400 million pounds of uranium oxide. The processing of the ore in uranium mills would generate approximately 10 million tons of finely ground waste solids called "tailings".

The existing federal and provincial regulatory requirements in Saskatchewan make it necessary that the uranium mining companies store tailings in such a way that they will not create any significant environmental problems during the operating life of a mill. Furthermore, it is expected that upon decommissioning, the tailings deposits would be so stabilised, as to make perpetual maintenance and monitoring of these deposits for the purpose of environmental protection unnecessary.

The federal and provincial environmental protection requirements, which regulate the uranium mining industry in Saskatchewan today, did not exist in the late 1950s and early 1960s. Therefore, the uranium mills which operated in Saskatchewan in those years discharged their tailings into small depressions or lakes without much regard for environmental protection. Two of these mills, Lorado and Gunnar, ceased operations in the early 1960s. The tailings depositions from these mills have been left unamended. They serve as examples of natural stabilising or destabilising processes which have occurred over the last two decades.

Preliminary investigations conducted jointly by Environment Canada and the Saskatchewan Department of the Environment in 1976 and 1978 (Ruggles et al, 1979) in the vicinity of dormant tailings deposit at Gunnar and Lorado Mills indicated that the tailings had caused a negative impact on the quality of the receiving water. However, it was also found that portions of these tailings had been colonized by indigenous flora. This was considered to be a significant aspect of the tailings-environment interaction. The existing natural vegetation cover can be expected to stabilize the tailings. For the Lorado deposit, an extensive growth of aquatic moss was observed covering most of Nero Lake, which had received the Lorado tailings.

These findings created concern and the initiative was taken by Environment Canada and the Saskatchewan Department of the Environment to approach these problems. In July of 1980, the University of Toronto was granted a contract, based on a research proposal consisting of three phases. The ultimate objectives of the research are given in point form below:

1. To investigate the role of the Nero Lake moss cover, with respect to acidification of the water, and retardation or enhancement of the movement of contaminants in the Lake. An understanding of the interactions of the Lorado Mill tailings with the water and the moss is sought.

2. To investigate the conditions which have led to the colonization of some parts of Gunnar Mill tailings by indigenous flora, but which left other parts completely barren.

3. Recommend procedures to stabilize the tailings at Lorando and Gunnar Mills, with emphasis on natural colonization of the tailings by indigenous flora.

The first phase of the study was brief and exploratory, and was completed between August 1980 and March 31, 1981. The results should delineate the specific direction and scope of further work, which is to be undertaken during subsequent years. This report contains the results from the first phase of the study.

## APPROACH AND OBJECTIVES OF PHASE I

In August 1980, both sites were surveyed in a five day field investigation. The investigation was carried out with the main objective to outline significant ecological aspects of the flora of both sites, in order to facilitate recommendations towards detailed work for the amelioration of both sites. Previous work by Ruggles et al, (1979) provided sufficient background information so that particularly important aspects of the waste sites could be assessed in such a brief survey. The aim was mainly to address specific areas, which are given for each site below:

1. Gunnar tailings in Mudford Lake

a) Identification of major dominant vegetation species growing on tailings.

b) Determination of concentration of selected elements in dominant vegetation and tailings to assess uptake of contaminants.

c) Description of physical and chemical surface characteristics to elucidate vegetation distribution.

2. Lorado tailings in Nero Lake

a) Determination of selected chemical characteristics of dry tailings of Lorado, water covered tailings in Nero Lake and Beaverlodge Lake sediments.

b) Delineation of stratification of the water and determination of physical-chemical characterisation of Nero Lake waters.

c) Identification of the moss, its distribution and occurrence pattern.

d) Determination of elemental concentrations in the moss and clarification of the relationship of the moss, tailings and water in Nero Lake.

e) Delineation of the effect of acidic water from Nero Lake discharging into Beaverlodge Bay.

For further details on the terms of reference of this work, see Appendix A.

## STUDY LOCATION AND BRIEF HISTORY OF THE SITES

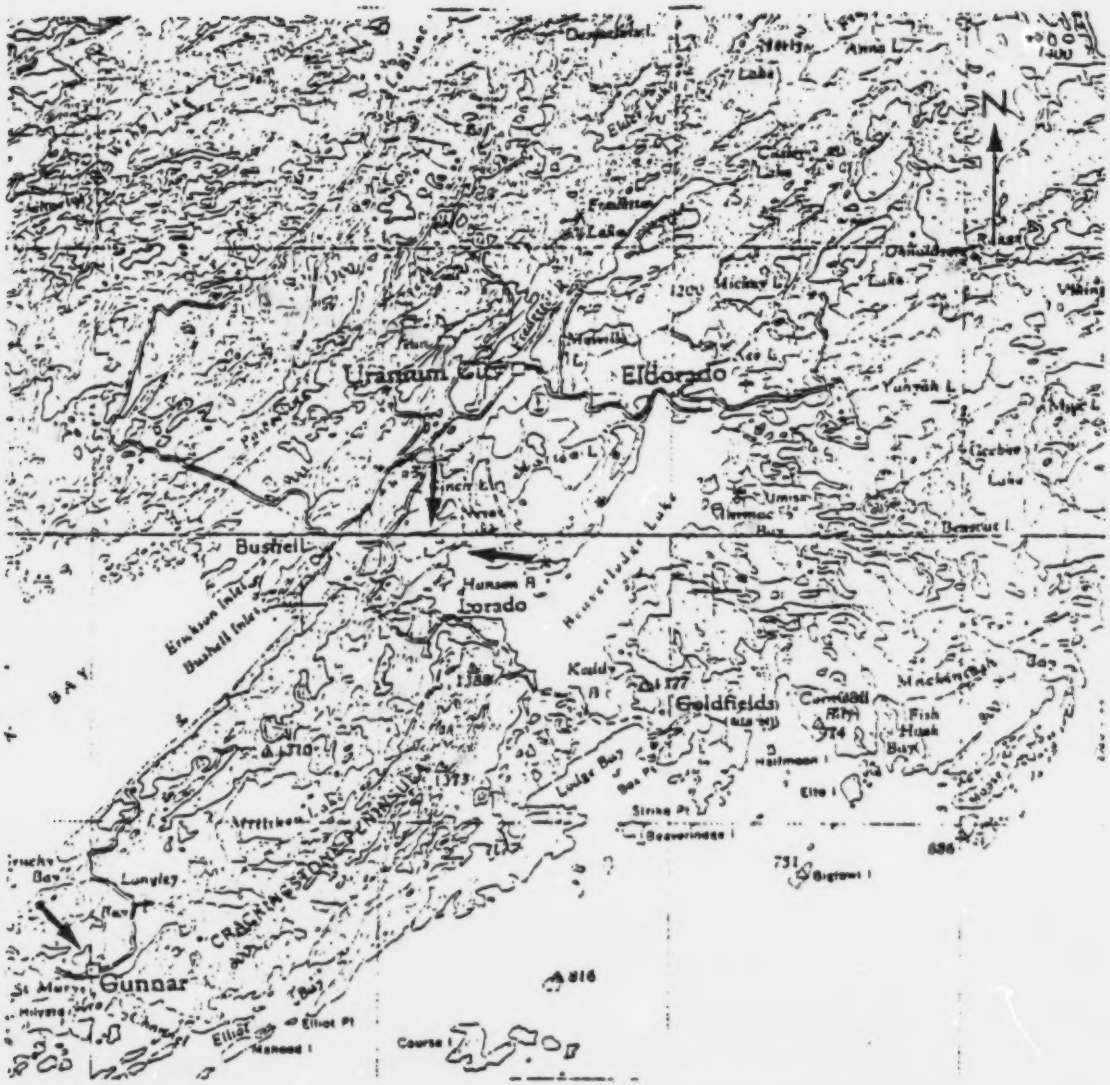
Both sites of abandoned tailings deposits are located in the Uranium City area, on the north shore of Lake Athabasca, Saskatchewan, Canada (Map 1).

The Gunnar Mill on Crackingstone Point, about 19.2 km southwest of Beaverlodge Bay started milling uranium ore in 1955. The tailings were discharged into Mudford Lake, 500 m northwest of the mill. Until early 1964, when the operation was closed, some estimated 4.5 million tons of tailings were produced. When the Mudford Lake basin was full the tailings spread into Langley Bay in Lake Athabasca, effectively dividing the western arm of Langley Bay by an area of exposed dry tailings. Tailings were discharged at 32 percent solids which assisted in the distribution down to Langley Bay.

The Lorado Mill was a custom operation, the ore originating from several mining operations, six major shippers of ore and some 25 small-scale mining operations. A total of 0.38 million tonnes were milled.

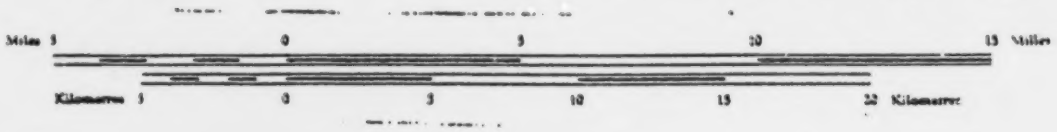
The mill was in operation for three years, from April 1957 to April 1960. Tailings were deposited into Nero Lake. At present two tailings beaches at the west end of the Lake exist, which border a surface area of approximately 10 ha of exposed tailings.

Both mills used sulphuric acid to leach the uranium and the tailings were discharged with a pH of 1.7 to 2.0 However, the quality of the ore milled at Gunnar and Lorado Mills was considerably different. The Lorado Mill tailings are at this time extremely acidic due to a high pyrite content. However, the Gunnar Mill tailings are




MAP 1: Location of Gunnar and Nero Lake and Beaverlodge Bay

Scale




* Referred to as Beaverlodge Bay

neutral. As a result, two tailings disposal sites present quite different situations. Lorado is effectively a lake disposal site with acid conditions. Gunnar is a site with mainly dry neutral tailings surfaces. Some tailings from Gunnar overflowed into Langley Bay, Lake Athabasca and are submerged there at present.

METHODS USED IN BOTH LOCATIONS

In the field survey samples of flora, sediments, tailings, water and soil were collected. The samples were analysed for various important parameters aiming to confirm previous years' results and to outline the ecological condition of the sites. All methods are standard practice and are given below in an abbreviated form. Detailed methods are outlined in Appendix B.

(a) Field observations

As only limited time was availalbe, observations were recorded photographically. Distances were approximated by pacing. Sampling locations were chosen based on visual impressions of significant surface and site characteristics.

(b) Tailings

Samples were obtained with a hand trowel, after excavating a small pit. The samples are considered composite grab samples. Details of preparation for analysis and analytical procedures are given in Appendix B.

(c) Vegetation

Vegetation specimens were collected for a preliminary documentation of existing flora primarily at the Gunnar site along Transect I to III indicated on Map 3. Dominant grasses were also secured for analysis. The specimens were pressed, identified and subsequently compared to specimens in the herbarium at the University of Toronto. The moss in Nero Lake was sampled with an Eckman dredge from the deeper locations and was preserved in plastic bags for transport to the laboratory. Detailed sampling procedures are given in Appendix B.

(d) Water

In shallow water, samples were taken directly with a one litre acid washed bottle. In deeper water a Van Dorne water sampler was used to collect a bottom sample and surface samples were taken at a standard depth of 1 m. The pH and conductivity were determined at each site and redetermined before filtration of the sample. Oxygen and temperature profiles were obtained in deeper water. Water was filtered through 0.45 µm filter papers within 6-8 h from the time of collection and acidified with concentrated nitric acid.

Further details of sample storage, transportation and analysis are given in Appendix B.

# 1. GUNNAR MILL TAILINGS SITE - RESULTS

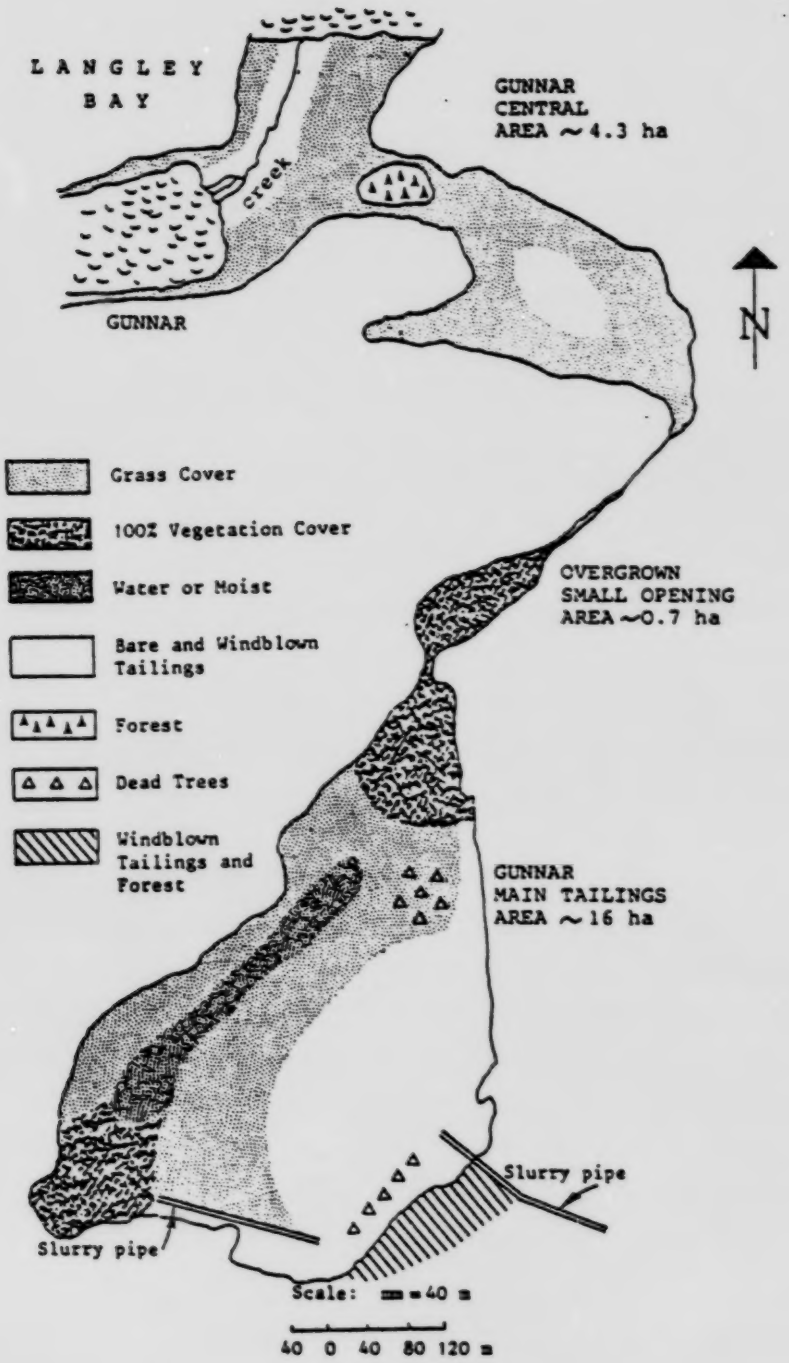
The Gunnar Mill tailings deposit flowed from the point of discharge into Langley Bay, Lake Athabasca. In this study the areas of dry exposed tailings are referred to as:

Gunnar Main: Gunnar Central; and, Langley Bay

On these sites three types of surface covers were identified. A rough estimate of the spatial distribution is shown on Map 2 and is described in detail below.

## 1.1 Surface Descriptions

1.1.1 Windblow Tailings: On the southeastern section of Gunnar Main the course fraction of the tailings are windblown. Small dunes of tailings have formed at the edge of the pond where the material is at present stopped by a rock outcrop (Map 2). Trees are covered with more than 30 cm of tailings at the edge of the southeast section. Note that originally the slurry pipe was at least 2-2.5 m high (arrow, Plate 1). In general, this section is bare, dry and slopes slightly down towards the grass and water-logged section. Very sparse grass hummocks (Plate 2) are found on the sandy tailings. The type of vegetation which dominates the remaining sections of the tailings pond does not seem to be established here (Plate 3). At the western edge of this bare section bordering the grass belt, the surface is often covered with an encrustment of white crystalline material (see Plate 8).



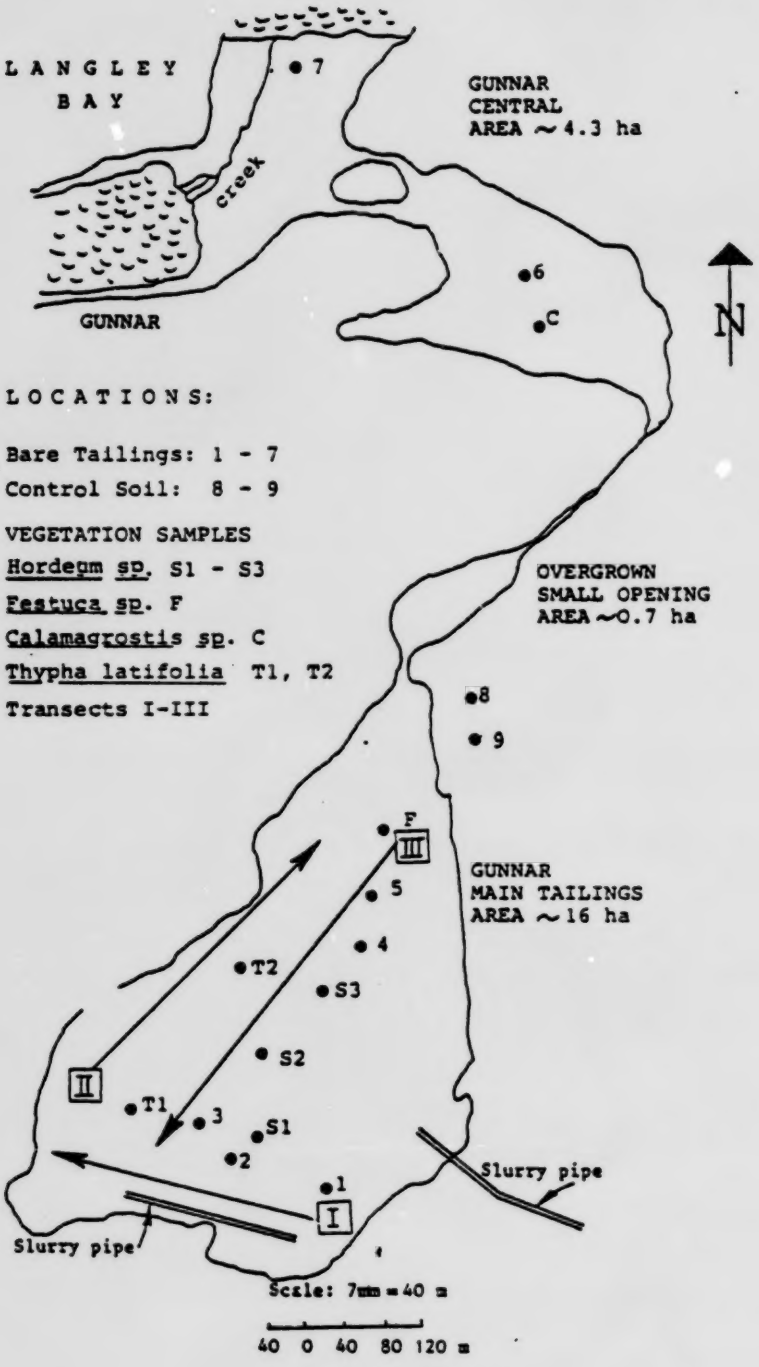

MAP 2: ESTIMATES OF SURFACE TYPE DISTRIBUTION

1.1.2 Grass covered tailings. On Gunnar Main Hordeum jubatum hummocks have sparsely colonised the outer bands of this section. Some portions are quite well stabilized with mainly Festuca rubra invading (Plate 4). Transects I to III were placed in this area (Map 3) to obtain a rough estimate of the vegetation cover, which was assessed visually. A brief description of each transect is given below.

Transect I: Bare windblown tailings cover the first third of the length of the transect east to west (Map 3). This gradually merges into a sparse vegetation cover, which is estimated to be 30 H. jubatum hummocks specimens and 100 F. rubra specimens in a 100 $m^2$ area. The sparse cover is maintained for the second third of the transect until the moist section is reached. The last third is overgrown with 100% vegetation cover. Encrustment and compacted tailings were sporadically encountered along the transect.

Transect II: It runs on the west side of the tailings pond in a south-north direction (Map 3). The vegetation cover is 100% at the start of the transect and decreases rapidly to 80% cover. After the first 150 m a 30% cover mainly consisting of grasses remains. The vegetation cover decreases in the next 200 m to 10% or less with many bare encrusted or compacted tailings areas. This low vegetation cover is maintained along the rest of the transect until a well vegetated section at the northern tip is reached. Encrustment and compacted tailings are spotty.

Transect III: This transect runs north-south.




MAP 3: LOCATION OF TAILINGS, SOIL, VEGETATION SAMPLES & TRANSECTS

It begins at the southern end of the well vegetated section of Gunnar Main. The border is quite abrupt as windblown tailings, with very sparse H. jubatum hummocks, cover the surface for the first 400 m of the transect. Large sections of this transect are covered with encrustment and compacted tailings. In the remaining 200 m of the southern part of the transect some other grass species are present together with H. jubatum.

Gunnar Central and Langley Bay: In these two sections of the tailings deposits, grasses have invaded the tailings. The dominant grass was identified as Calamagrostis inexpansa in the Central area, different to that of F. rubra and other grasses unidentified which occurred on the Main tailings pond. Hordeum jubatum was only found on Gunnar Main tailings, but was virtually absent on Gunnar Central and Langley Bay tailings (Plate 5). The dominant grass in Langley Bay was identified as Deschampsia flexuosa. This separation by tailings locations of dominant grass species needs further study and confirmation. Identification of all the plants collected is given in Table 1.

Plate 6 shows the typical character of the border between the grass cover and the windblown tailings. In the foreground some of the white encrustment areas are visible.

To determine whether obvious differences, apparent on the surface, could be found also in depth strata of the tailings, several pits were excavated in the border region of the grass belt (Plate 7, 8 and 9; Map 3). The profiles of the pits are very similar and consist of a mixture of

Table 1. Plants collected from Transect I-III on Gunnar and associated sites

GUNNAR MAIN TAILINGS

*Alnus crispa* Pursh
*Achillea Millefoluim* L.
*Carex rostrata* Stokes
*Epilobium angustifolium* L.
*Festuca rubra*
*Hordeum jubatum*
*Juncus balticus* Willd
*Moneses uniflora* (L.) Gray
*Plantago major* L.
*Rumex occidentalis* S. Watts
*Triglochin palustris* L.

GUNNAR CENTRAL TAILINGS

*Calamagrostis inexpansa* A. Gray
*Carex aquatilis* Wahl

LANGLEY BAY TAILINGS

*Deschampsia flexuosa* (L.) Trin

"fine" and "coarse" tailings. Layers, generally to a depth of 2-5 cm, can be distinguished and sometimes differ in colour (grey or red). Roots of grasses penetrate roughly 10-20 cm.

In Plate 10 the absence of all the tree crowns at approximately the same height can be observed. These 1-2 m high dead tree trunks are not a general characteristic of the Gunnar Main tailings pond. Other dead tree stands are complete trees. The significance of this observation is not clear at this point; however, it is sufficiently unusual to merit a note.

1.1.3 One-hundred percent vegetation cover. The southern tip of the main pond is well covered with sedges, horsetails, grasses and some shrubs. The same type of vegetation also covers the northern tip of the Gunnar tailings. The edges of the tailings pond are intensely green with vegetation. Some parts of the western edge of the tailings support stands of alder, indicating relatively high moisture content. The water source is probably surface drainage and run-off from the rock outcrop bordering the tailings pond.

The tailings which have spilled down toward Langley Bay are dry with no evidence of a permanent creek. However, the vegetation in the small overgrown opening is very dense and lush (Map 3). The amount of tailings is most likely small and there is little evidence of tailings remaining as can be seen on Plate 11.

1.1.4 Surface water and moist section. There is a series of ponds on the west edge of Gunnar Main (Map 3) surrounded by cattail colonies (Plate 12). Water characteristics and heavy metals were determined for two of the ponds and other water samples associated with the Gunnar site are summarized in Table 2. The concentrations of the Gunnar site are given together with Beaverlodge Bay so that they can be compared. Nickel was the only metal consistently associated with the Gunnar Main water; the concentrations are not considered elevated. Conductivity is high in the pools (T1, T2; Map 3), the water is quite alkaline, but less so than in Fookes Lake (Eldorado active tailings pond).

Table 3 summarizes further element analysis and water characteristics. The Gunnar Main seepage is characterized by high concentration of manganese and has a somewhat lower pH than the surface waters on Gunnar Main. Calcium and magnesium are high in all water on Gunnar Main and are likely to be the major contributing elements to the high conductivity.

In Langley Bay Creek, where the water flows over the tailings, no differences in the concentrations of the elements determined were noted, when compared to the water of St. Marys Channel, a control location.

Table 2. Gunnar Mill and Beaverlodge Bay water samples

| Location | Map code | Analysis code | pH | Conductivity | Copper µg/ml | Nickel µg/ml | Cobalt µg/ml | Lead µg/ml |
|---|---|---|---|---|---|---|---|---|
| GUNNAR | | | | | | | | |
| Cattail central pool | T2 | TG-11 | 8.4 | 7,200 | - | 0.066 | - | - |
| Cattail south pool | T1 | TS-11 | 7.7 | 2,400 | - | 0.013 | 0.013 | - |
| South seepage | | GSS-11 | 6.6 | 3,650 | 0.006 | 0.045 | - | - |
| Langley Bay Creek | | GLB-11 | 6.5 | 120 | - | - | - | - |
| Control, Lake Athabasca St. Mary's Channel | | LAC-11 | 7.6 | 70 | - | - | - | - |
| Cattail Fookes | | TF-11 | 9.3 | 1,400 | - | - | - | - |
| Meadows, Fresh $H_2O$ Spring | | TE-11 | 8.8 | 1,200 | - | - | - | - |
| BEAVERLODGE BAY | | | | | | | | |
| Sediment Site 3, 5.5 m deep 500 m out in Bay | 7 | BS-11 | 7.7 | 220 | - | - | - | - |
| | | BS-01 | 7.0 | 220 | 0.020 | - | - | - |
| Precipitate | 7a | BP-11 | 7.2 | 220 | - | - | - | - |
| Collection site | | BP-01 | 7.6 | 230 | - | - | - | - |
| Control Lake | 9 | CLL-11 | 7.8 | 170 | - | - | - | - |
| Lorado mine discharge | L | LMD-11 | 5.6 | 600 | - | 0.038 | 0.043 | - |

Table 3. Water characteristics of Gunnar and surroundings determined in mg/l, not included in the maps

| | pH | Map Code | U | Mg | V | Al | Mn | Ca | Cond. µ mhos/ cm |
|---|---|---|---|---|---|---|---|---|---|
| Typha pond Central | 8.4 | T2 | 3.2 | 1260 | ≤0.014 | ≤0.4 | ≤0.4 | 412 | 7200 |
| Typha pond south | 7.7 | T1 | 2.7 | 153 | <0.005 | <0.13 | <0.13 | 318 | 2400 |
| Gunnar seepage south | 6.6 | none | 5.1 | 400 | <0.01 | <0.3 | 16.8 | 306 | 3650 |
| Langley Bay Creek | 6.5 | 7 | 0.006 | <4 | <0.002 | 0.12 | <0.06 | 12.6 | 120 |
| Lake Athabasca St. Marys Channel | 7.6 | none | ≤0.002 | 2.5 | <0.001 | 0.11 | <0.03 | 5.5 | 70 |
| Bowen (1960) natural background | | | 0.001 | 4.1 | 0.001 | 0.24 | 0.012 | 15 | - |

## 1.2 Tailings Characteristics

1.2.1 Physical and chemical determinations. In Table 4 results are presented of pH and conductivity determined from the tailings slurries, together with percent moisture loss and loss on ignition on tailings material. As a relatively small number of samples was available for analysis, the measurements were repeated on each sample and both values are reported (columns Numbered 1 and 2). All sample locations are given on Map 3.

The pH of the tailings is generally neutral to alkaline with some slightly acidic locations. The tailings were discharged during the operation of the mill with a pH of 1.7 to 2 as a 32% solids slurry (Griffith, 1967). All three locations (Gunnar Main, Central and Lanley Bay) are neutral at present.

Samples 4, 6 and 7 have high conductivities (10,000 umhos/cm) as compared to the other tailings samples which are consistently around 3,000 µmhos/cm. Only the windblown tailings samples (Numbers 1 and 2) and the tailings around the T. latifolia have lower ranges of 1,500 µmhos/cm. The control soils, collected in the vicinity are lowest in conductivity within about 100 µmhos/cm (Map 3). Further interpretation of vegetation association with determined parameters is not possible. The samples are grouped according to their association (vegetation, water or dry). The percent of moisture loss is quite uniform, considering the variable nature of the parameters. Bare tailings (samples 1 to 7) cannot be considered drier than samples obtained around vegetation roots. The moisture holding

Table 4. Gunnar tailings and soils characteristics

| Site description | Map code | Analysis code | pH | | Conductivity µ mhos/cm | | Moisture loss (%) | | L.O.I. (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Determination | | | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Gunnar dry tailings | 1 | GW-1,2 | 7.2 | 7.02 | 600 | 520 | 0.12 | 0.33 | 0.63 | 0.61 |
| | 2 | GE-1,2 | 6.5 | 6.65 | 1,500 | 1,800 | 3.91 | 4.42 | 2.37 | 2.24 |
| | 3 | GB-1,2 | 4.3 | 4.61 | 2,800 | 3,000 | 29.89 | 25.06 | 3.45 | 2.94 |
| | 5 | GGP-1,2 | 7.1 | 7.01 | 2,800 | 2,700 | 14.87 | 18.23 | 0.89 | 0.84 |
| | 4 | GSP-1,2 | 6.4 | 7.01 | 9,200 | 10,000 | 21.32 | 22.79 | 3.93 | 3.70 |
| | 6 | GCB-1,2 | 3.95 | 4.11 | 10,000 | 10,000 | 5.91 | 17.54 | 1.98 | 1.39 |
| | 7 | GLB-1,2 | 6.0 | 5.79 | 2,200 | 2,400 | 20.80 | 22.07 | 1.23 | 1.29 |
| | T1 | TS-3 | 7.2 | 7.00 | 1,100 | 940 | 13.41 | 22.43 | 0.80 | 0.58 |
| | T2 | TG-3 dry | 7.0 | 6.80 | 1,500 | 1,000 | 18.08 | 17.56 | 0.74 | 0.42 |
| Gunnar waterlogged | T2 | TG-3 wet | 6.6 | 6.54 | - | 2,400 | - | 24.66 | 1.46 | 1.32 |
| Gunnar control soil | 8 | CH-1 | 5.8 | 5.9 | 105 | 86 | 3.41 | 4.02 | 8.94 | 16.20 |
| | 9 | CL-1 | 6.0 | 6.4 | 85 | 91 | 6.38 | 5.06 | 10.58 | 7.62 |
| | - | CW-1 | 5.55 | 6.0 | 72 | 30 | 2.17 | 1.35 | 2.57 | 2.61 |
| Grasses/ foxtails | C | GC-3 | 4.9 | 6.20 | 4,800 | 2,800 | 3.96 | 4.89 | 0.97 | 0.96 |
| | F | GG-3 | 7.7 | 7.8 | 10,000 | 10,000 | 15.35 | 12.72 | 1.87 | 1.61 |
| | S1 | FS-3 | 7.1 | 6.81 | 2,800 | 2,300 | 3.98 | 7.57 | 1.33 | 1.15 |
| | S2 | FC-3 | 6.2 | 6.52 | 4,200 | 3,400 | 29.07 | 25.22 | 2.76 | 1.91 |
| | S3 | FN-3 | 6.9 | 7.01 | 5,300 | 4,200 | 28.04 | 23.15 | 2.72 | 2.57 |
| Ace Creek | | FA-3 | 8.0 | 8.19 | 620 | 680 | 2.12 | 2.53 | 0.95 | 0.59 |

capacity of tailings appears better than the control soils (numbers 8 and 9); however, the windblown tailings are dry (sample #1).

The organic matter which is estimated by loss on ignition (L.O.I. %) is generally low compared to control soils. It does not appear, from the limited number of samples taken that the locations with vegetation are significantly higher in organic matter than bare tailings.

1.2.2 Concentrations of elements. Neutron activation was used to screen for the following elements: Co, U, Dy, Ba, Ti, Sr, I, Br, Mg, Na, V, Al, Mn, Cl, Ca. With atomic absorption spectroscopy heavy metals Co, Ni, Cu and Pb were determined. Only those elements are considered which were above the analytical detection limit.

The concentrations of the elements determined are reported as ranges and are represented on maps, according to the sampling location. The choice of ranges was made to facilitate classification of data points into meaningful intervals. A given interval includes those data points greater than or equal to the lower bound, but less than the upper bound.

The elements can be divided in two groups. The first group represents the elements where concentrations are higher than control soil samples. The second group consists of elements which are present in tailings in concentrations lower than the control sites.

To evaluate vegetation on Gunnar tailings, these two groupings may be useful. However, caution should be used since the data set is small, and only two control soils

were analysed from the area. One sample was taken from an elevated area on a rock outcrop, and the second from a depression in the forest (Map 3). All the statements made about elemental concentration of the tailings have to be viewed as preliminary.

Each element is briefly commented on. Background concentrations of elements in soil or rock given by Bowen (1966) and Jonasson (1973) are used to discuss each element and its distribution as represented on Maps 4-13.

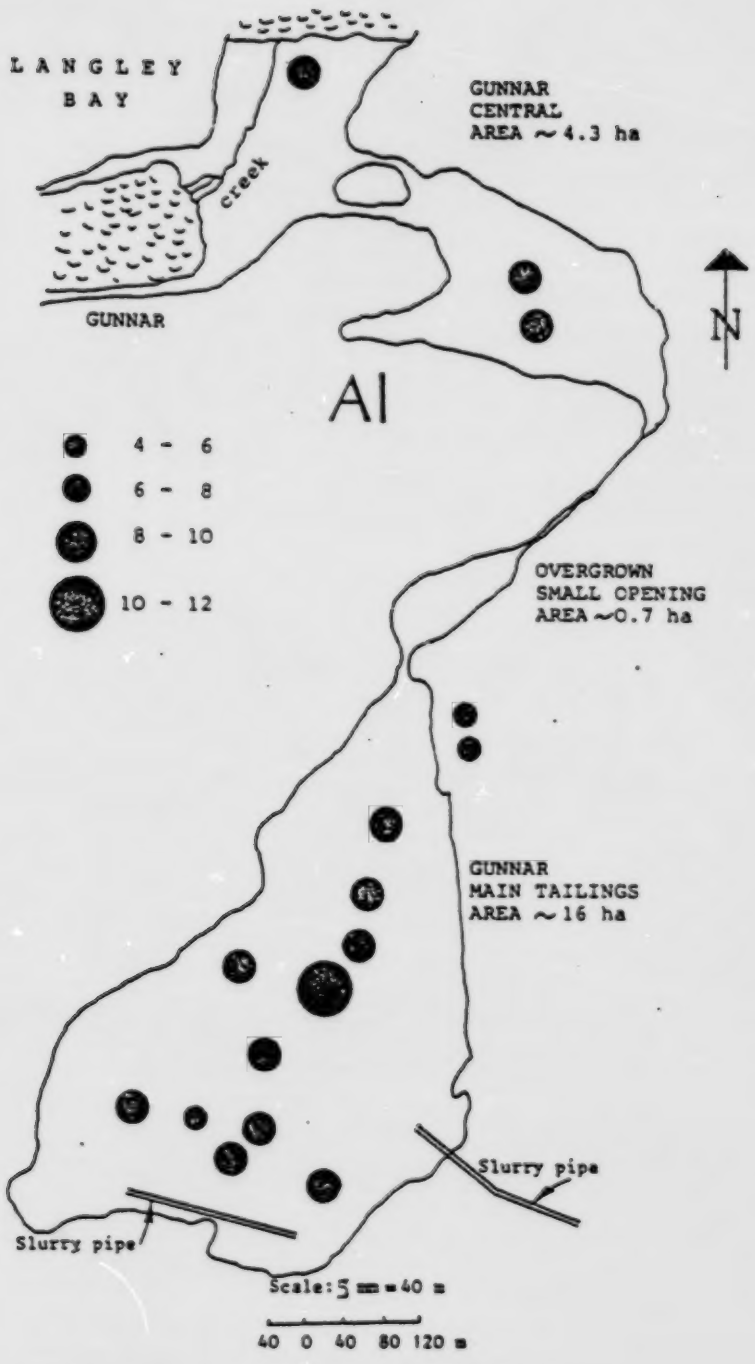
Group 1: Concentrations higher on tailings than on control soils.

Aluminum, Map 4: Aluminum in the tailings on Gunnar Main are in the expected range of concentrations in soil.

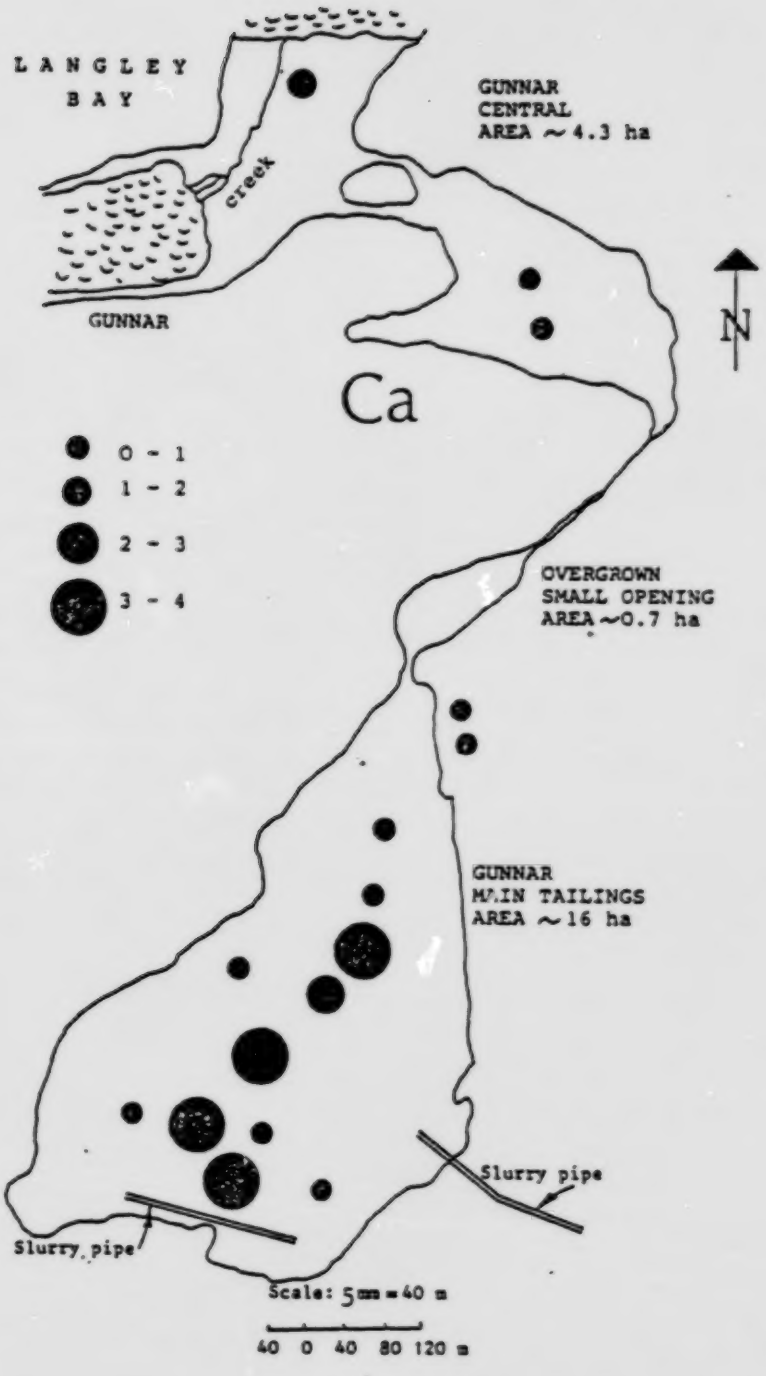
Calcium, Map 5: The tailings have a sufficient amount of calcium to support vegetation. Langley Bay and Gunnar Central appear to have distinctly lower concentrations ranges of calcium than Gunnar Main.

Copper, Map 6: Copper concentrations in the tailings are not high. The even distribution of the tailings of 20 to 40 ppm is striking compared to the distribution of other elements. Water copper concentrations are slightly elevated, particularly in the seepage on the south end.

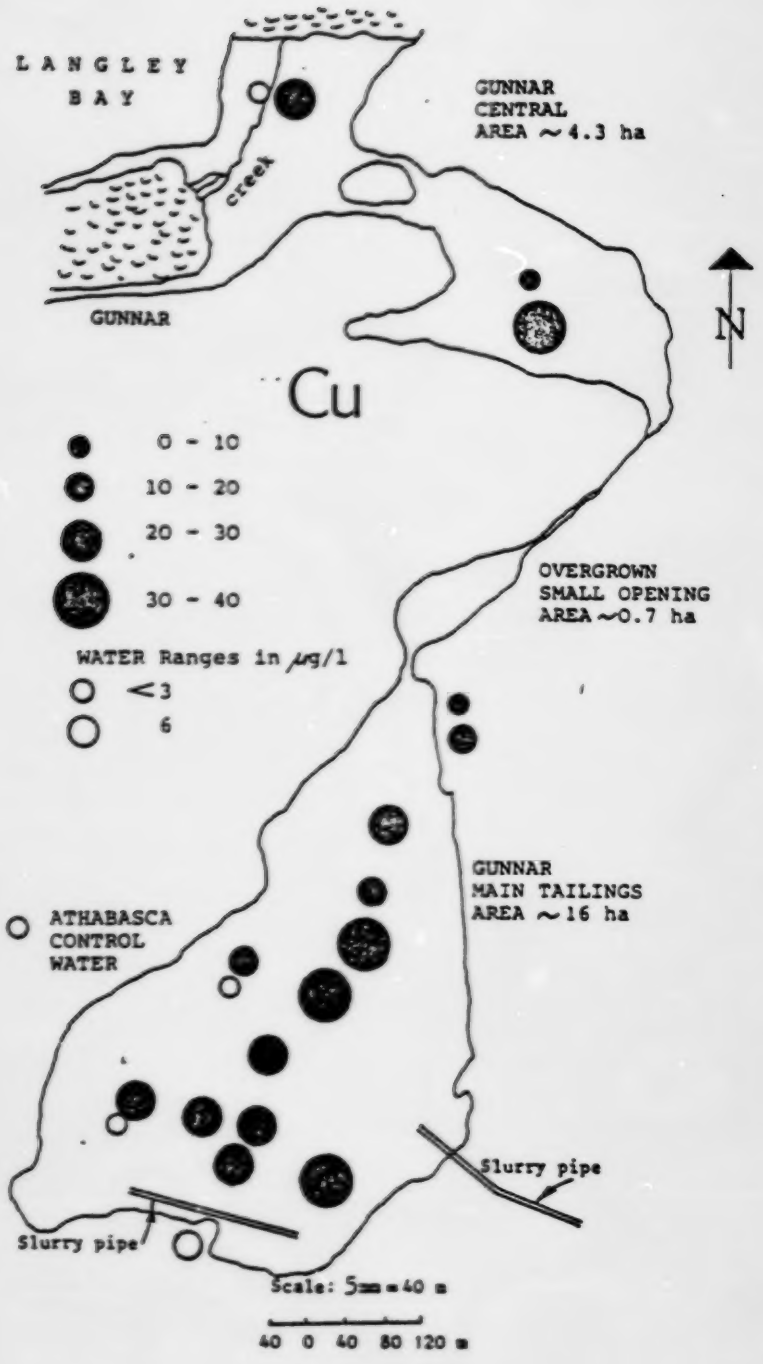
Lead, Map 7: Lead appears to be high in concentration in the tailings. Bowen (1966) gives background concentrations as 10 ppm and Jonasson (1973) values for



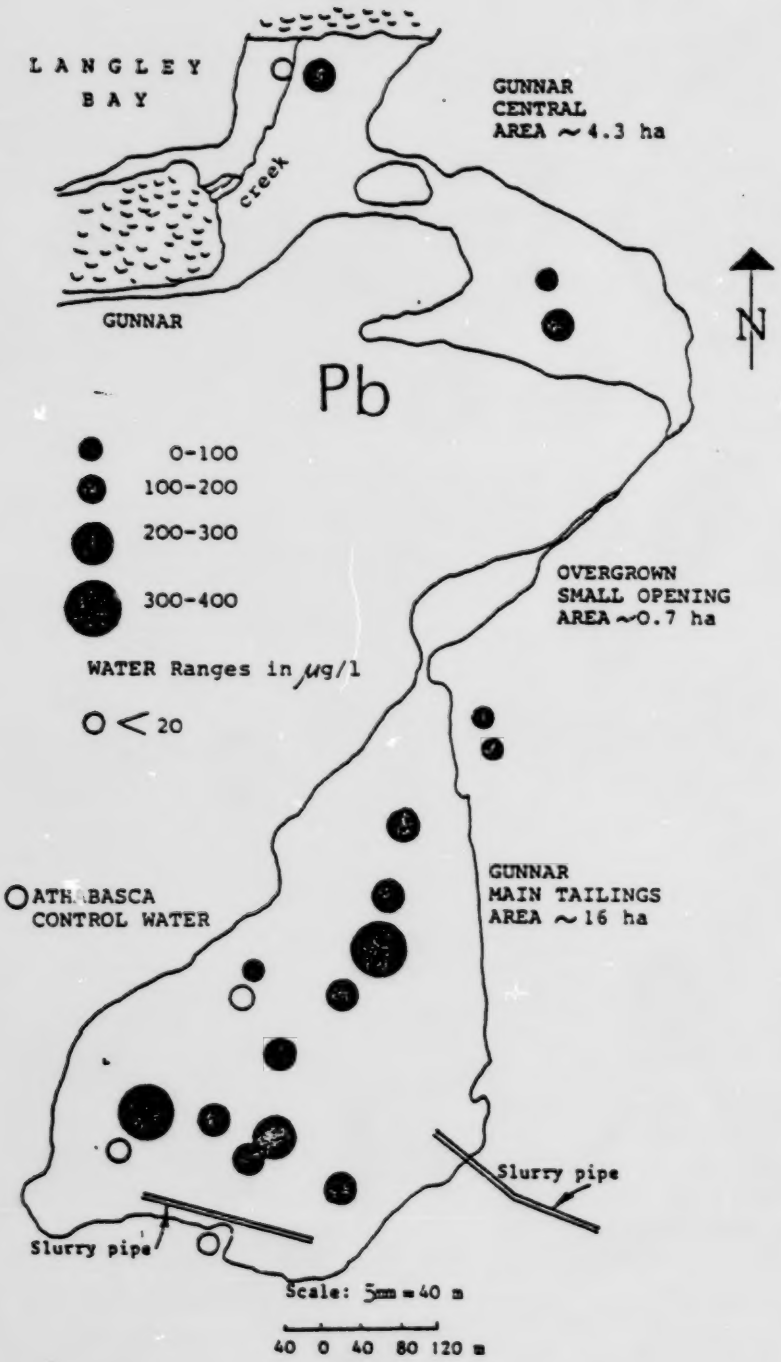

MAP 4: TAILINGS/SOIL ranges in percent for Al.



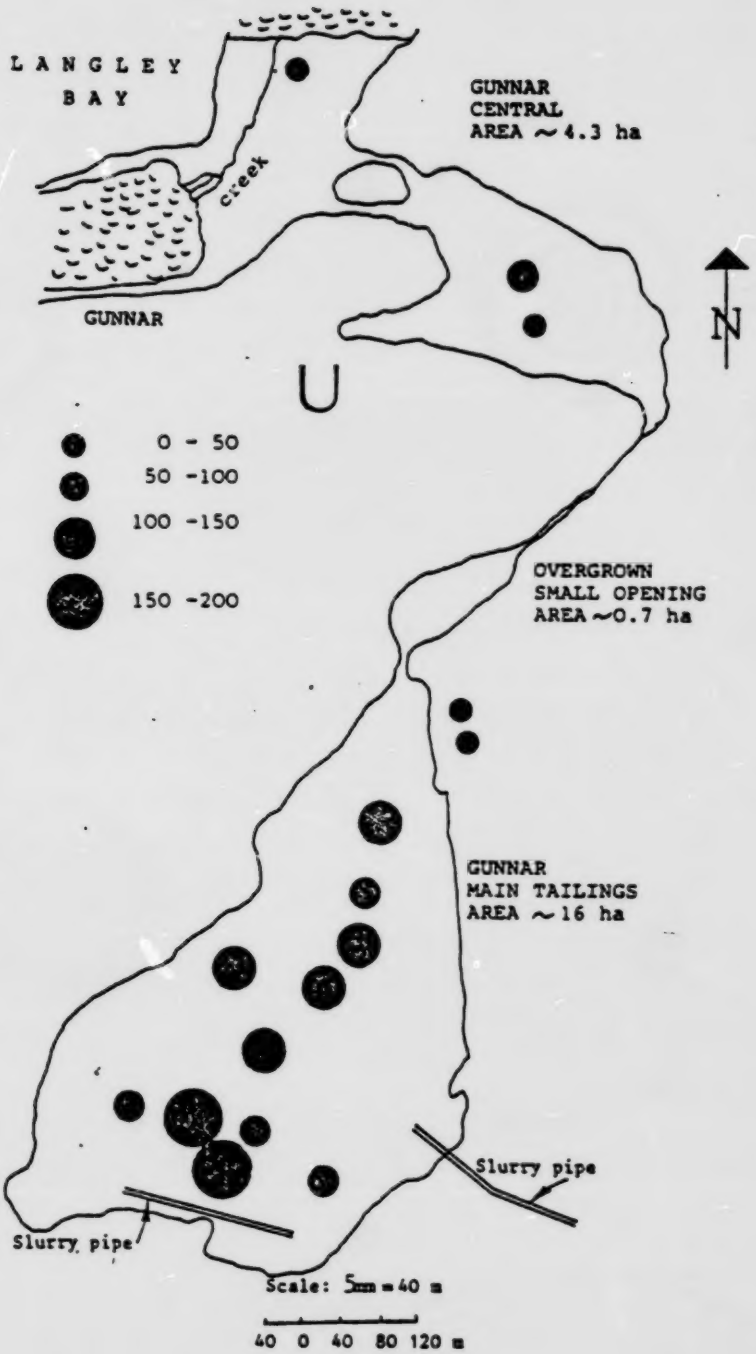

MAP 5: TAILINGS/SOIL ranges in percent for Ca.




MAP 6: TAILINGS/SOIL ranges in µg/g for Cu.




MAP 7: TAILINGS/SOIL ranges in µg/g for Pb.




MAP 8: TAILINGS/SOIL ranges in ug/g for U.

mineralised gravel as 20 ppm. In abandoned tailings sites, Pb was often found to be elevated. The tailings concentrations were determined in the majority in a range of 100-200 ppm or higher. The water concentrations, however, are all below 20 ppb which can be expected under alkaline conditions.

Uranium, Map 8: Uranium concentrations are as expected higher than background values. Bowen (1966) quotes a concentration of 1 ppm for soils. However, when compared to other abandoned tailings sites, the reported concentrations are normal. The uranium water concentrations are low, as expected under alkaline conditions.

Group 2: Elements of higher concentrations in control samples than on tailings.

In this group of elements possible deficiencies in the substrate for vegetation are assessed.

Cobalt, Map 9: The concentration of cobalt in tailings are low but they are within the ranges of a minimum requirement for plants. The water concentrations are in the normal range, possibly elevated in the surface ponds where T. latifolia was collected.

Magnesium, Map 10: Magnesium concentrations range from normal to high for soils and are similar for all locations.

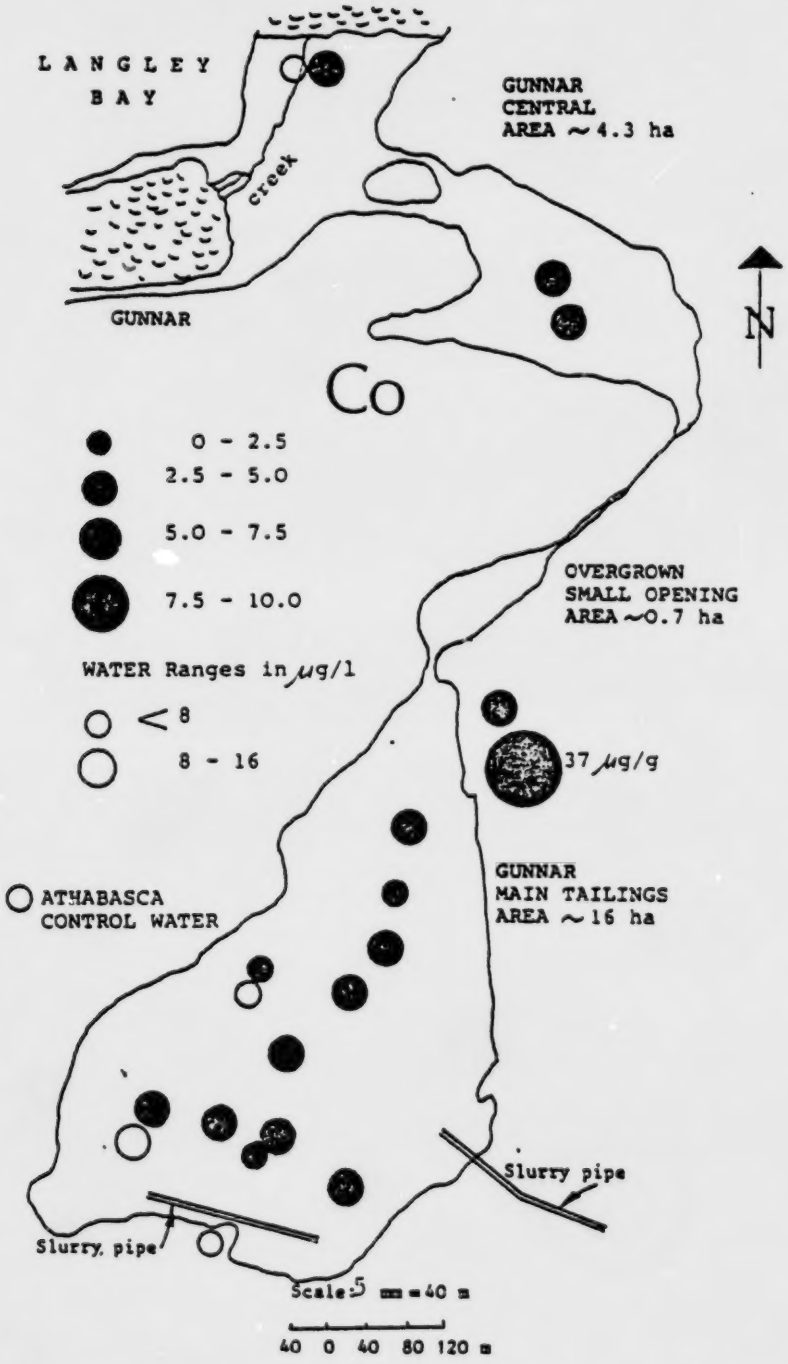
Manganese, Map 11: Manganese concentrations are low in the tailings, and consistent at all locations. Compared to Bowen (1960) who quotes 850 ppm and Jonasson (1973) who quotes 910-1600 ppm for a variety of soils, the majority of samples have a value below 500 ppm.

Nickel, Map 12: Nickel presents an interesting situation, in that the control soil is significantly elevated, but the tailings concentrations are all low. The water concentrations are in normal fresh water ranges.

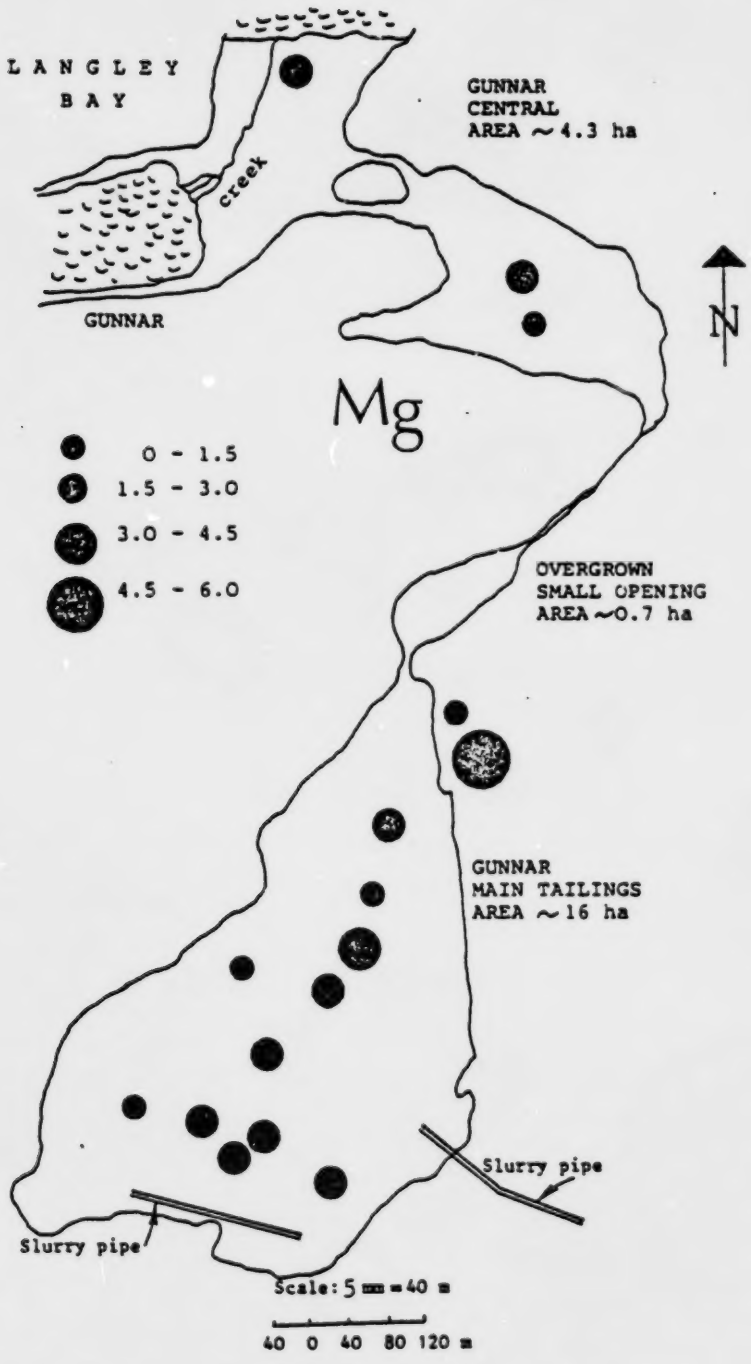
Vanadium, Map 13: Vanadium is present in the tailings from a low to normal range. The control soils represent average values compared to Bowen (1966) who quotes 100 ppm.

In viewing all elemental maps, concentration ranges do not appear to reflect the surface characteristics described in the earlier sections. No consistent pattern emerges. Vegetation tailings samples cannot be differentiated from bare tailings samples, based on the elemental concentrations determined in this brief survey.

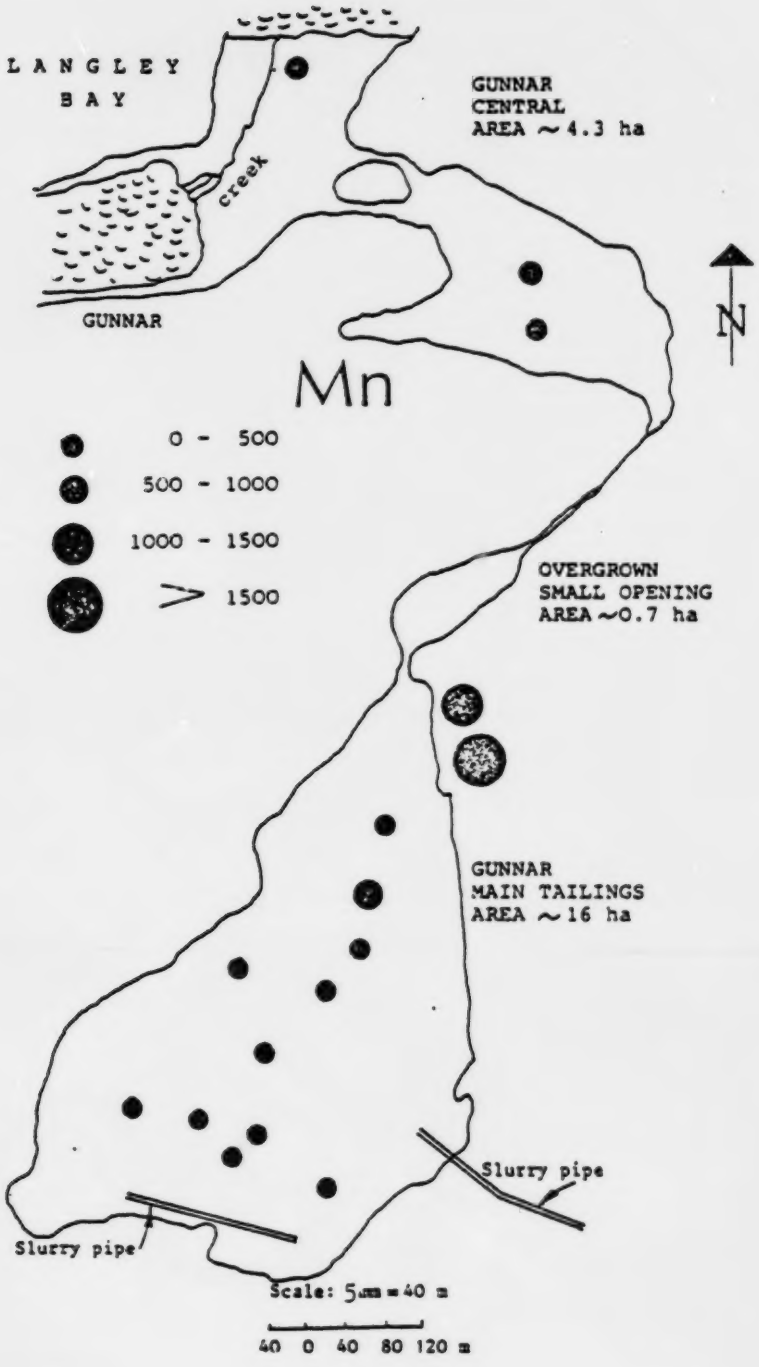
1.2.3 Vegetation uptake of elements. Table 5a presents the results of the analysis of four H. jubatum hummocks. The different parts of the hummock seeds, stems, leaves and roots were separated and reported individually for each collection. The sample size and variation does not warrant a treatment of the data statistically. Ace Creek (Eldorado), an abandoned tailings site, has been revegetated with relative success.



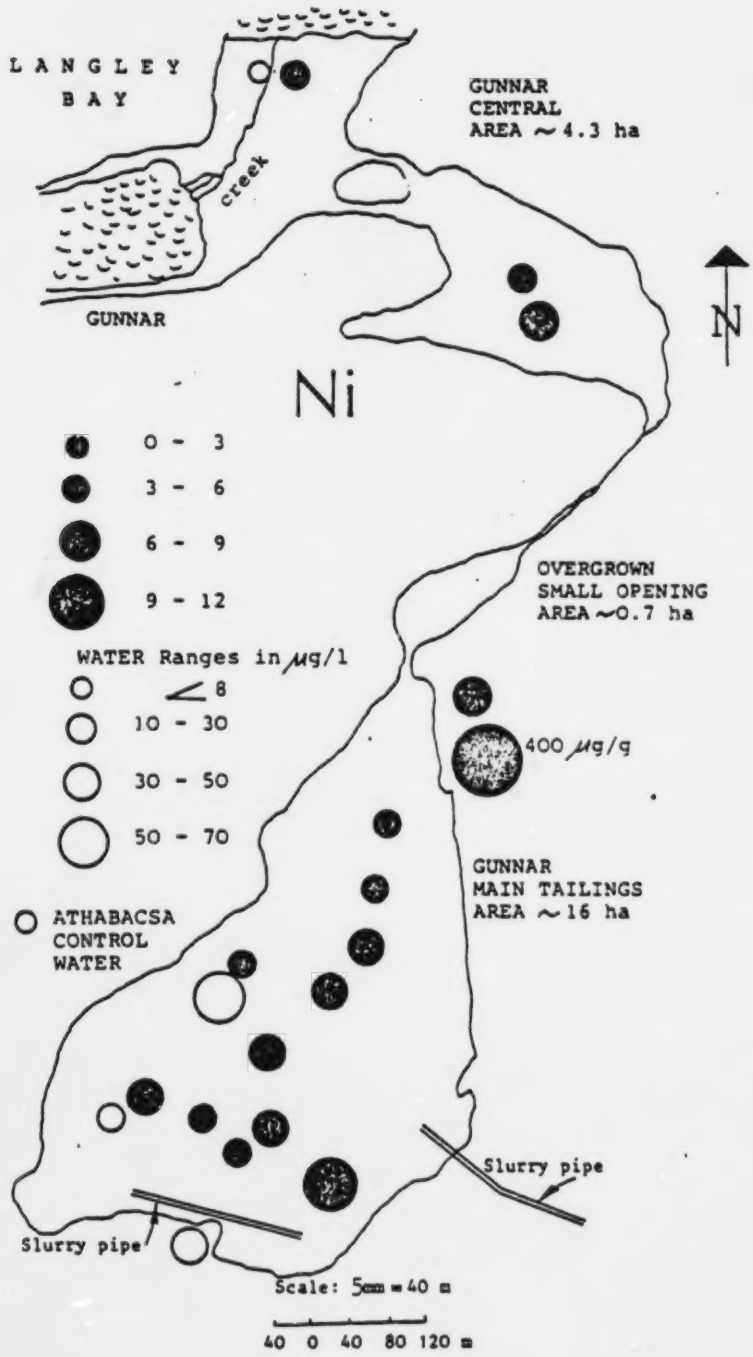

MAP 9: TAILINGS/SITE ranges in ug/g for Co.



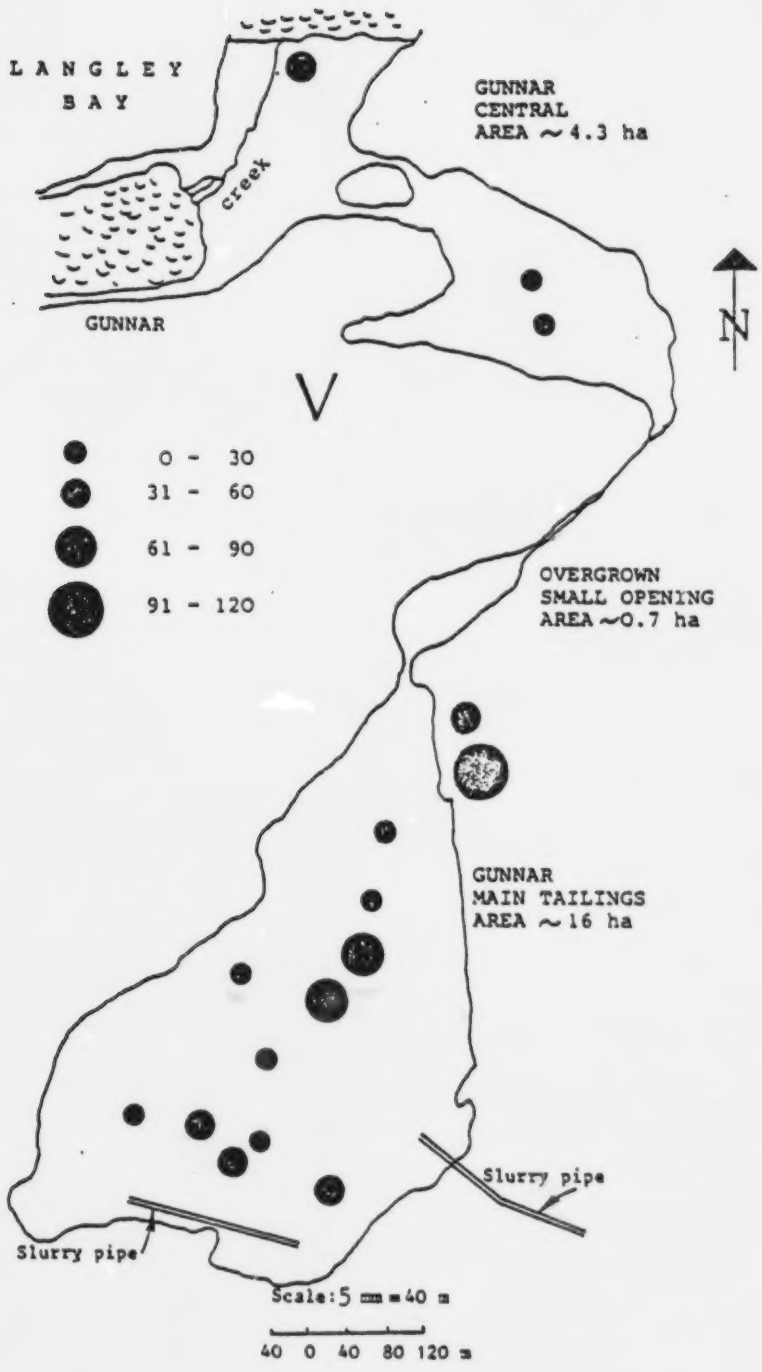

MAP 10: TAILINGS/SOIL ranges in percent for Mg.




MAP 11: TAILINGS/SOIL ranges in ug/g for Mn.




MAP 12: TAILINGS/SOIL ranges in ug/g for Ni.




MAP 13: TAILINGS/SOIL ranges in ug/g for V.

Table 5a. Distribution of some elements and concentration factors in *H. jubatum* growing on Gunnar tailings and Ace Creek tailings (Eldorado) in µg/g

| | Copper | | Nickel | | Lead | | Uranium | | Vanadium | | % Calcium | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Foxtails: GUNNAR NORTH Substrate (pH 6.9 | 35.2 | | 7.0 | | 148 | | 113 | | 69 | | 2.89 | |
| Fruit | 5.7 | *0.16* | 3.4 | *0.49* | 3.5 | *0.02* | 2.7 | *0.02* | <0.2 | *<0.003* | 0.070 | *0.02* |
| S3 Leaves and stems | 7.6 | *0.22* | 5.9 | *0.84* | 10.1 | *0.07* | 195 | *1.73* | 3.4 | *0.05* | 0.81 | *0.28* |
| Roots | 112 | *3.2* | 20.1 | *2.87* | 93.4 | *0.63* | 700 | *6.19* | 7.4 | *0.11* | 0.39 | *0.13* |
| GUNNAR CENTRE Substrate (pH 6.2) | 20.6 | | 7.0 | | 121 | | 150 | | 27.6 | | 3.62 | |
| Fruit | 11.0 | *0.53* | 2.6 | *0.37* | 3.4 | *0.03* | 0.71 | *0.005* | 0.5 | *<0.02* | 0.10 | *0.03* |
| S2 Leaves and stems | 70 | *3.40* | 30.7 | *4.4* | 20.1 | *0.17* | 9.1 | *0.06* | 0.9 | *0.03* | 0.20 | *0.06* |
| Roots | 65 | *3.2* | 11.3 | *1.6* | 70.3 | *0.58* | - | - | - | - | - | - |
| GUNNAR SOUTH Substrate (pH 7.1) | 23.7 | | 7.5 | | 200 | | 85 | | 21 | | 0.60 | |
| Fruit | 5.6 | *0.24* | 1.9 | *0.25* | 9.6 | *0.05* | 3.2 | *0.04* | 0.73 | *0.03* | 0.11 | *0.18* |
| S1 Leaves and stems | 17 | *0.72* | 10.9 | *1.5* | 21.9 | *0.11* | 89 | *1.0* | 1.4 | *0.07* | 0.19 | *0.32* |
| Roots | 40 | *1.7* | 8.3 | *1.1* | 104 | *0.52* | 350 | *4.1* | 3.4 | *0.16* | 0.21 | *0.35* |
| ACE CREEK, ELDORADO Substrate (pH 8.1) | 57.3 | | 31.9 | | 267 | | 164 | | 870 | | 1.72 | |
| Fruit | 7.8 | *0.14* | 1.8 | *0.06* | 7.0 | *0.03* | 6.4 | *0.04* | 1.47 | *0.002* | 0.14 | *0.08* |
| Leaves and stems | 14.8 | *0.26* | 4.82 | *0.15* | 22.2 | *0.08* | 36.8 | *0.22* | 11.2 | *0.013* | 0.18 | *0.10* |
| Roots | 245 | *4.3* | 39.6 | *1.24* | 210 | *0.79* | 374 | *2.3* | 45 | *0.052* | 0.66 | *0.38* |

Italic numbers are cf's based on the substrate concentrations.

Effectively, all elemental concentrations in the tailings are higher in Ace Creek than on the Gunnar Mill sites. Roots are somewhat higher in concentrations of Cu, Ni and U than the tailings. The concentrations factors (cf's) are, however, not strikingly high and consequently the hummocks cannot be considered accumulators based on the reported cf's. For lead, vanadium and calcium there is little uptake in the roots. The aerial parts of the plant are generally lower in elemental concentration than the roots. The fraction of the concentration which decreases is larger for the fruits than for the stems and leaves. The H. jubatum hummock (S2 Gunnar Main, Map 3) is an exception. Here the concentrations of the elements found in leaves and stems are higher than the concentration in the roots and also in the tailings. The sample may have been contaminated or represents an unusual situation.

Two representative hummocks of other dominant grasses were also analysed. Table 5b summarizes the results in the same way as the four Hordeum hummocks were given in Table 5a. It is apparent that these species accumulate less Cu, Ni and Pb in the roots than H. jubatum. Unfortunately, the amount of material collected was not enough for fruits and roots to provide sufficient material to be analysed for U, V, Ca. A comparison of elements in the stems and leaves is made between these hummocks and H. jubatum. It appears that these dominant species are slightly lower in elemental concentrations in stems and leaves. The fruits for the elements Cu, Ni and Pb indicate that these species have higher absolute concentrations than those which were determined in the seeds of H. jubatum.

Table 5b. Grasses dominant on Gunnar Main and Gunnar Central tailings. Element conc. µg/g

| | Copper | | Nickel | | Lead | | Uranium | | Vanadium | | Calcium | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Calamagrostis* sp. | | | | | | | | | | | | |
| GUNNAR CENTRAL | | | | | | | | | | | | |
| Substrate (pH 5.2) | 32.9 | | 8.6 | | 124 | | 49 | | 25 | | 0.62 | |
| Fruit | 14.9 | *0.45* | 8.1 | *0.94* | 7.0 | *0.06* | - | - | - | - | - | - |
| Leaves and stems | 6.3 | *0.19* | 7.3 | *0.85* | 7.0 | *0.06* | 8.0 | *0.16* | <1.9 | *<0.08* | 0.49 | *0.79* |
| Roots | 37 | *1.1* | 10.0 | *1.2* | 33.4 | *0.27* | - | - | - | - | - | - |
| GUNNAR MAIN *Festuca rubra* | | | | | | | | | | | | |
| Substrate (pH 7.8) | 26.1 | | 5.5 | | 103 | | 111 | | 21 | | 0.88 | |
| Fruit | 15.0 | *0.57* | 3.2 | *0.58* | 19 | *0.18* | - | - | - | - | - | - |
| Leaves and stems | 11.4 | *0.44* | 23.9 | *4.3* | 10.8 | *0.10* | 44.6 | *0.40* | <0.6 | *<0.03* | 0.13 | *0.15* |
| Roots | 40 | *1.5* | 16.8 | *3.1* | 94.6 | *0.92* | - | - | - | - | - | - |
| Bowen (1966) | | | | | | | | | | | | |
| Rock-soil ranges Rock | 4-55 | | 20-75 | | 7-20 | | 0.45-2.2 | | 20-135 | | 22100-302000 | |
| Soil | 20 | | 40 | | 10 | | 1 | | 100 | | 13700 | |
| Bowen (1966) | | | | | | | | | | | | |
| Plant concentrations | 14 | | 3 | | 2.7 | | 0.038 | | 1.6 | | 18000 | |

Because there was only one hummock of each species collected and analysed, it is clear that the comment is only a conjecture.

The Typha latifolia collected on Gunnar and Eldorado showed accumulation in the roots. The absolute concentrations are much higher in Gunnar than in Eldorado. The Eldorado T. latifolia grew on rocky shores where no tailings could be collected.

The results are given in Table 5c, together with T. latifolia plants growing on abandoned uranium mill tailings which were collected in the Bancroft and Elliot Lake areas.

Comparing the plant parts, rhizomes, leaves, stems and seeds among the four sites, it appears that concentrations of copper, nickel, cobalt and lead are similar for all tailings locations. The standard deviations overlap in all cases greatly so that these concentrations can be considered as identical. Because of the small sample size, further interpretation of the data is not justified.

Comparing these preliminary results with values given in the literature, Hutchinson (1975) gives some concentrations ranges for aquatic plants. These are for copper 2.5-74 ppm for nickel, 17.7-44 ppm, for cobalt 0.27 to 8.3 ppm and for lead 2.0-53 ppm. If all plant parts are considered, the concentrations of heavy metals in T. latifolia do not deviate from these ranges, with the exception of lead, which has been identified as a potential problem in uranium mill tailings. (Kalin, 1980 submitted).

Table 5c. Concentrations of Cu, Ni, Pb and Co in ppm (dry weight) in *T. latifolia* parts

| | Seeds | Stems | Leaves | Roots | Rhizomes |
|---|---|---|---|---|---|
| COPPER | | | | | |
| Eldorado active n=4 | 9.0 ±1.0 | 6.3 ±2.5 | 5.6 ±2.3 | 16.0 ±5.2 | 5.9 ±1.0 |
| Gunnar inactive n=2 | 11.4 ±3.0 | 5.2 ±0.4 | 4.2 ±0.6 | 36.1 ±22.9 | 7.6 ±3.1 |
| Bancroft inactive n=4 | 11.4 ±2.8 | 11.5 ±6.2 | 8.6 ±3.3 | 46.8 ±35.0 | 7.3 ±4.7 |
| Elliot Lake inactive n=4 | 5.6 ±1.8 | 3.0 ±1.5 | 4.8 ±0.6 | 45.0 ±46.0 | 6.3 ±5.5 |
| NICKEL | | | | | |
| Eldorado active n=4 | 1.2 ±0.3 | 2.9 ±1.7 | 2.6 ±2.5 | 4.2 ±0.9 | 2.2 ±0.9 |
| Gunnar inactive n=2 | 2.7 ±1.0 | 0.75 ±0.1 | 1.1 ±0.5 | 3.6 ±1.2 | 0.9 ±0.4 |
| Bancroft inactive n=4 | 1.7 ±0.9 | 1.2 ±0.5 | 3.1 ±1.0 | 6.6 ±4.1 | 1.5 ±0.7 |
| Elliot Lake inactive n=4 | 1.8 ±1.1 | 1.0 ±0.46 | 4.5 ±1.9 | 17.8 ±15.0 | 2.7 ±3.4 |
| LEAD | | | | | |
| Eldorado active n=4 | <1.2 | 1.8 ±1.3 | 2.1 ±0.4 | 52.2 ±41.0 | 6.6 ±6.7 |
| Gunnar inactive n=2 | 1.7 ±0.3 | 1.8 n=1 | 1.9 ±0.7 | 740.0 ±141.0 | 28.0 ±18.0 |
| Bancroft inactive n=4 | 1.8 ±0.5 | 2.5 ±1.5 | 4.09 ±0.4 | 214.8 ±212.0 | 11.7 ±11.7 |
| Elliot Lake inactive n=4 | 2.1 ±0.7 | 6.2 ±1.3 | 9.2 ±2.5 | 665.0 ±499.0 | 36.2 ±32.3 |
| COBALT | | | | | |
| Eldorado active n=4 | <0.3 | <0.4 | <0.2 | <1.5 | 1.1 ±0.6 |
| Gunnar inactive n=2 | <1.0 | <0.2 | <0.2 | 6.2 ±3.2 | <0.6 |
| Bancroft inactive n=4 | 0.69 ±0.1 | 1.3 ±0.45 | 2.75 ±1.99 | 14.7 ±10.1 | 0.64 ±0.23 |
| Elliot Lake inactive n=4 | 0.90 ±0.38 | 0.70 ±0.55 | 1.7 ±0.72 | 15.4 ±7.6 | 0.9 ±0.6 |

## 1.3 Gunnar Discussion

The results obtained in this survey are based on a small number of samples analysed and a brief site visit. Therefore, the conclusions presented here are preliminary and are made with a considerable amount of caution.

A selected flora has invaded the tailings surfaces of all Gunnar sites in the past 17 years. Sparsely distributed over roughly two-thirds of the Gunnar Main tailings are mainly the species Hordeum jubatum and Festuca rubra. In general, the species richness is low on all tailings surveyed (Table 1). This finding is similar to abandoned tailings ponds in Bancroft and Elliot Lake areas. A more comprehensive vegetation sampling would be necessary to allow a better comparison. Windblown loose tailings cover the remaining surface area on Gunnar Main, and this area needs to be ameliorated (Map 2).

The northern and southern tips are covered completely with vegetation. This may be due to the actual location which has more protection from winds by the surrounding landscape and possibly higher moisture retentions. The moisture content determined in the other tailings sections (Table 4),did not show any particular moisture gradient, including the samples collected close to the ponds. Therefore, moisture alone cannot be the main factor influencing vegetation cover.

Some dominant species of the well vegetated northern and southern tips were the sedges Juncus balticus and Carex rostrata. Further extensive mats of Triglochin

palustris, a species which is found in very moist habitats, colonize this area. The existence of these species support the suggestion that water is important. In effect, a moisture gradient might have been found if these areas had been sampled.

Considering the introduction of water to the tailings, the results presented in Table 4 indicate that the material is readily dissolved in water from the tailings. The pH of the water will probably not be altered drastically by the neutral tailings, however, the conductivity may be increased. This could be undesirable to the existing vegetation and for the revegetation. Clearly the two existing vegetation cover types, the grass cover and the 100% vegetation cover, are very different communities. Both areas are dominated by vegetation of very different growth requirements. A detailed study of both these covers is necessary before the revegetation efforts commence. These studies should include the vegetation communities on Gunnar Central and Langley Bay, to broaden the data base on invading species in those areas. It appears, from the identification of visually perceived dominant grasses, that the three tailings deposits are differentiated by distinct species groups. This observation has to be quantified in the future, but it may be very significant in amelioration efforts of Gunnar tailings.

The Gunnar Central tailings are stabilized almost completely by a sparse grass cover. Only some barren patches remain and the tailings in these patches are compacted and partly covered with encrustment.

The dry tailings of Langley Bay exhibit a similar cover to Gunnar Central. This statement refers only to the northeastern section of Langley Bay tailings, since there was no time left on this field trip for an inspection of the southern and western portion of the exposed tailings.

As improvement is planned for this area of wind-blown tailings on Gunnar Main, some comments are made regarding the potential toxicities of the metals. In general, no toxic metal concentrations on these tailings are encountered by the vegetation. However, tolerance for lead and uranium may be required as both these elements are considerably elevated (Maps 7 & 8). The alkaline nature of the tailings may alleviate potential toxic effects. Lead is less available to plants in alkaline conditions as its solubility is reduced. This appears to be the case, shown by the relatively low root concentrations of the vegetation analysed (Tables 5a and 5b). The T. latifolia concentrations of lead (Table 5c) are indicative of potential problems if water accumulates in ponds and the terrain becomes semi-aquatic.

The indigenous grasses on the tailings do not appear to be acculator species for any of the elements analysed. The sparse cover of grasses is clearly a reflection of the harsh conditions on the tailings. The nutrient status has not yet been determined. Nutrients are possibly limiting the vegetation. However, nutrient deficiencies in these tailings are presumably far less restrictive for vegetation than such characteristics as texture of the tailings, moisture retention, and exposure of the sites.

# 2. LORADO - NERO LAKE - BEAVERLODGE BAY - RESULTS

## 2.1 Description and Field Observations

2.1.1 Tailings surfaces of the Lorado site. On the Lorado site exposed dry tailings cover approximately 10 ha. In the first year of the operation of the mill in 1957, an estimated 86,000 short tons of tailings were dumped into a small lake and completely filled it. This tonnage roughly represents the present exposed tailings surface. From 1958-1960 an estimated 335,000 short tons were discharged untreated at a pH of 1.7-2 into Nero Lake. The tailings tonnage was estimated based on production data given by Griffith (1967). Detailed calculations are given in Appendix B.

The surface of the tailing is bare (Plate 13). Two small ponds were found which were covered with algal growth and moss protonemata. The water has a pH of 2.3 and a conductivity of 12,000 µmhos/cm. The totally barren tailings are a result of highly pyritic ore which was milled in the Lorado mill. It is estimated that these tailings contain 5% sulphur (Taylor, pers. comm.). A striking surface characteristic is several areas of white crystals (Plate 14), which are possibly magnesium sulphate, remnants of the $U_3O_8$ extraction process. The tailings are frequented by vehicles (Plate 16), which is considered undesirable.

On the southern and northern edges of the exposed tailings Typha latifolia survived. The tailings beaches shown in Plate 15 are covered with dead moss.

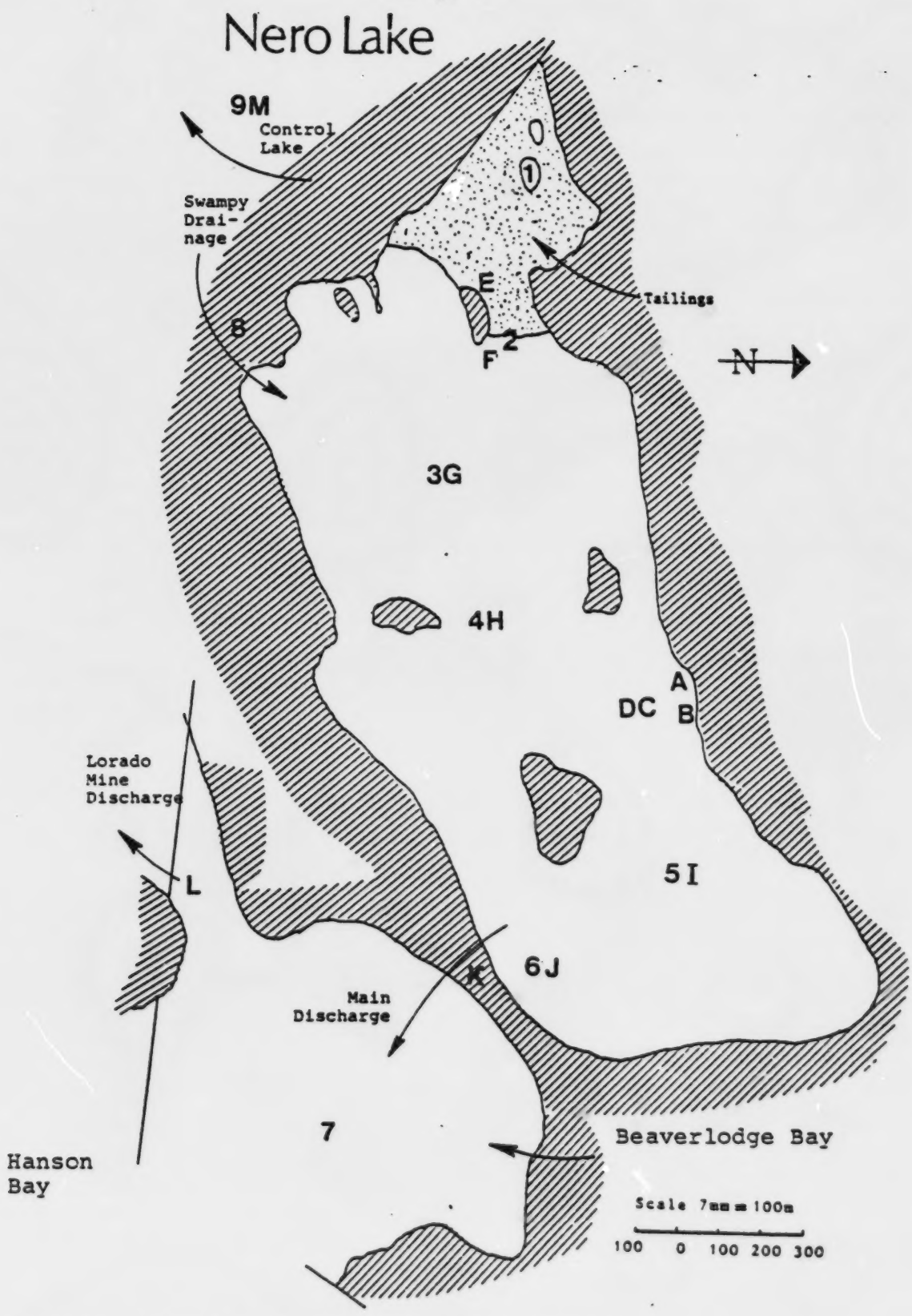
2.1.2 Nero Lake. Tailings beaches are located on the

west end of Nero Lake (Map 13). The rest of the shoreline is uniformly dominated by a black spruce swamp community (Plate 17). The protected shorelines are covered with a moss carpet (Plate 18). The rocky and shallow gravelly shorelines are free of moss growth. The moss was identified as Leptodyctium riparium (Hedw.) Warnst. Further observations on L. riparium and some analytical results are given in a later section. The eastern shoreline of Nero Lake is gravelly and borders a narrow berm, through which Nero Lake water is discharged into Beaverlodge Bay. Plate 19 gives a visual impression of the berm, through which the seepage occurs.

Berm surface water characteristics given in Table 6 show that the same pH and conductivity occur here as in Nero Lake (see Table 8). Note that a swamp draining into Nero Lake has a pH of 7.1 and a conductivity of 280 µmhos/cm. (Map 13, oc. 8). The drainage from Nero Lake at other times of the year is not only through surface flow but also through a culvert which was built to accommodate the overflow, (Plate 20).

Table 6. Water on the berm between Nero Lake and Beaverlodge Bay

| | pH | Conductivity µ-mhos/cm |
|---|---|---|
| Leaving Nero Lake | 3.4 | 2300 |
| 1st puddle on berm | 3.4 | 2600 |
| 2nd puddle on berm | 3.5 | 2200 |
| At point of discharge to Beaverlodge Bay | 3.4 | 2050 |




MAP 14: Location of water and moss samples.

2.1.3 Beaverlodge Bay. The extent of the discharge from Nero Lake was determined by pH and conductivity measurements. The data describes the extent of the surface water plume and are given in Table 7. It appears that in late August, the surface plume has a dimension of 12 m wide and 15-20 m long. The immediate effects appear small and the incoming water equilibrates rapidly to values common to Beaverlodge Bay (Table 8).

A rough estimate of the flow rate of the water leaving Nero Lake through the berm was made. The volume of surface water in August 1980 was estimated to be approximately 30 l/sec. However, on the shore whitish material on stones and gravel extended at least 50 m on both sides from the point of discharge, indicate a larger plume of increased water flow during various seasons. The white material on the stones is shown in Plate 21 and is probably the result of rapid neutralization of the acidic water entering from Nero Lake.

Further associated with the discharge appears to be a cover of whitish material on the bottom of the lake; this covering is found to extend 50-70 m from the shore at the point of discharge. Near the shore the lake slope is very gentle and mats of this material can be closely investigated. Plate 22 shows the covering on a stone and on a mat of vegetation. All stones in this area are covered with a layer of vegetation mat at least 1-2 cm thick when wet (Plate 23). The mats and organic debris are fastened together by the whitish yellow cover. An arrow indicates a layer of oxidized material at the bottom. A brief discussion of this observation is given below.

Table 7. Zone in Beaverlodge Bay influenced by Nero Lake discharge

| | Centre | | 6 m to right | | 6 m to left | |
|---|---|---|---|---|---|---|
| | cond. | pH | cond. | pH | cond. | pH |
| Point of Nero Lake discharge on shore | 2050 | 3.4 | 380 | 7.0 | 265 | 7.6 |
| 3 m out in Beaverlodge Bay | 650 | 4.5 | 350 | 6.5 | 285 | 7.8 |
| 6 m out in Beaverlodge Bay | 350 | 5.8 | 335 | 6.7 | 245 | 7.6 |
| 9 m out in Beaverlodge Bay | 330 | 6.2 | 300 | 6.8 | 235 | 7.7 |
| 12 m out in Beaverlodge Bay | 310 | 6.7 | - | 7.6 | 235 | 7.6 |
| 15 m out in Beaverlodge Bay | 270 | 7.1 | | | | |
| 20-25 m out in boat in Beaverlodge Bay | 250 | 7.6 | | | | |

Note: cond. = conductivety in μ mhos/cm, measured with YSI, Model 33, S-C-T meter.

Table 8. Water characteristics of Beaverlodge Bay

| Location | | pH | Conductivity μ mhos/cm | Dissolved oxygen ppm | Temperature C |
|---|---|---|---|---|---|
| Shore east bay Site M | | 7.8 | 225 | 9.4 | 19 |
| 10 m out: | S | 7.8 | 220 | 9.4 | 18 |
| depth 2.5 m | B | 8.2 | 220 | 8.9 | 18 |
| Centre site L | S | 7.7 | 220 | 8.8 | 18 |
| depth: 5.5 m | B | 6.9 | 220 | 8.8 | 18 |
| secchi: 5.5 m | | | | | |
| 75-100 m from Nero Lake discharge Site K | S | 7.6 | 220 | 8.9 | 19 |
| depth: 2.5-3 m | B | 7.2 | 230 | 9.1 | 19 |
| secchi: 2.5 m | | | | | |

Note: Locations are given on Map 2; S = surface; B = bottom

Upon microscopic examination, it was evident that the largest fraction of this cover was organic material. The mat could be referred to as a periphytic detrital aggregate. Bowen (1979) describes similar characteristics in a tropical lake. Filamentous blue-green algae were a major component of both aggregates. In deeper waters flocculent whitish material can be found often in close vicinity to Potamogeton sp. Bowen (1979) also refers to the associaton of Potamogeton sp. Dense growth of Potamogeton sp. in Beaverlodge Bay produces a striking contrast to the whitish periphytic detrital aggregate. Dredging in deeper portions of the area revealed loose aggregates of the same material. Bowen (1979) describes a drastic increase of algal volume as the littoral slope increases. It is suggested that this could also be the case for Beaverlodge Bay.

The shore on the east side of Beaverlodge Bay was inspected for periphyton growth and material was scraped from stones. The stones did not show mats similar to those found near the discharge zone nor are the stones covered with periphytic detrital aggregate. Microscopic examination of the stone-scrapings revealed a normal periphyton community.

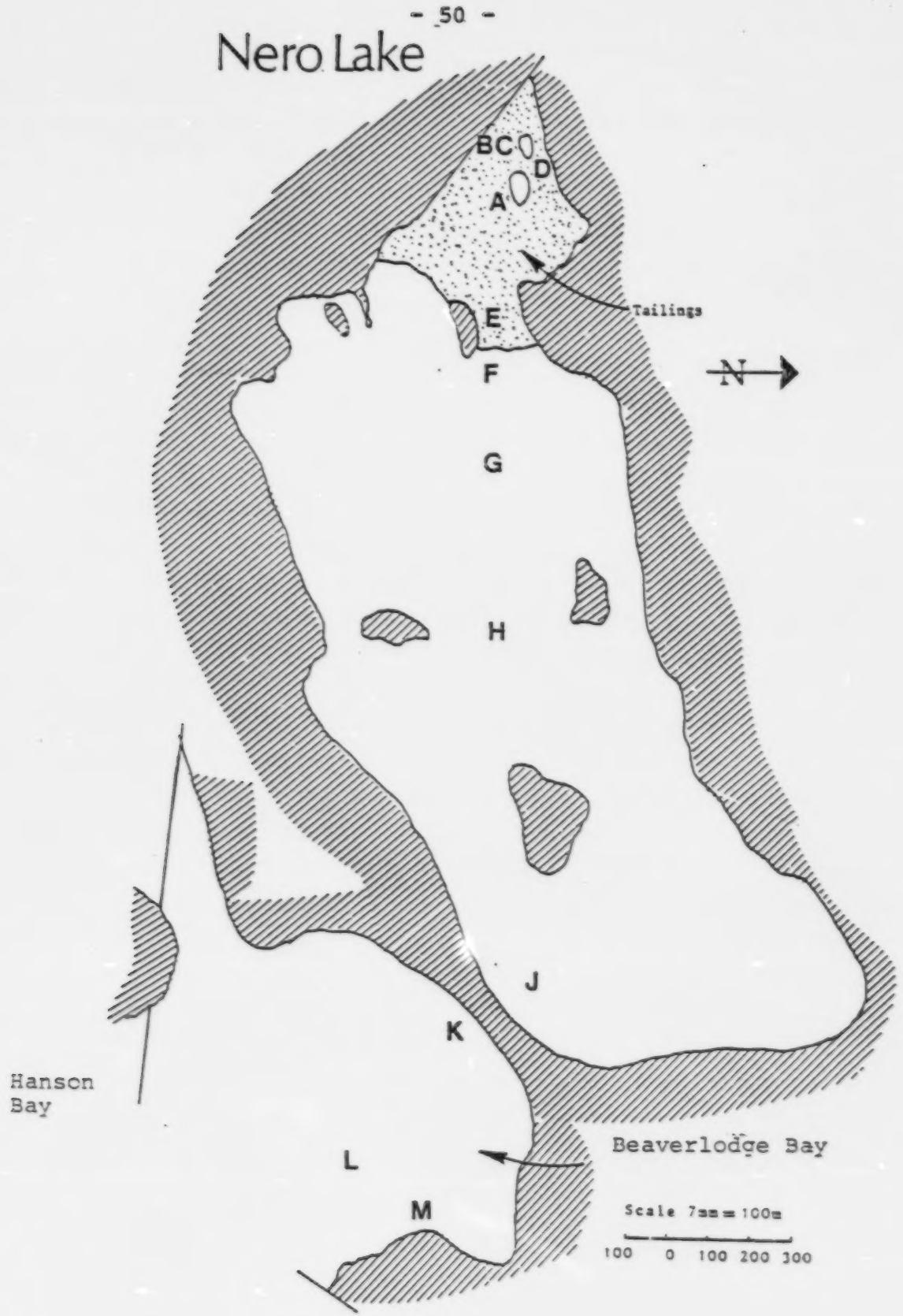
## 2.2 Chemical characteristics

The emphasis in this part of the survey was placed on delineating and describing the connection of the exposed Lorado tailings, the submerged tailings in Nero Lake and the discharging waters from Nero Lake into Beaverlodge Bay.

A few sampling locations placed on an east-west transect and control locations were identified and sampled to provide background values for the area. Further, it was necessary to gain a sense of perspective on the acidic nature of the waters of Nero Lake inhabited by the aquatic bryphyte. Most results and measurements are, therefore, reported together for all three locations.

2.2.1 Tailings - sediments. Tailings and sediments were collected in locations given on Map 14 (letters A to M). The acidity of the exposed tailings (pH 2.5-3.3) and a high conductivity is evident from the results given in Table 9. Some tailings dredged from the bottom of Nero Lake were notably less acidic (samples G & H). Also the conductivity of submerged tailings is significantly lower in these than in the dry tailings. Both these findings can be expected after 20 years of disposed tailings in the lake.

The moisture content is relatively low on the surface of the dry tailings and the organic matter (L.O.I.%) is varied. Loss on ignition is not a particularly reliable indicator for the organic material, given the high sulphur content of the tailings. However, the determinations are more reliable for samples K, L and M sediments in Beaverlodge Lake. The periphytic detrital aggregate in Beaverlodge Lake and the stone scrape material have approximately 20% organic material. It should be noted that E is the site where moss is washed up on the tailings beach, and site J, at the east end of the lake, is free of tailings and was covered with moss and algal debris. Both locations naturally are in the same range for L.O.I.%.




MAP 15: Location of the tailings and sediment samples.

Table 9. Tailings characteristics Lorado - Nero Lake - Beaverlodge Bay

| Site description and map codes | | Analysis code | pH | | Conductivity µ mhos/cm | | Moisture loss (%) | | L.O.I. (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| Lorado dry tailings | E | NWC-4 | 2.8 | 2.91 | 10,000 | 9.300 | 32.81 | 31.95 | 19.34 | 18.02 |
| | D | NPC-4 | 2.7 | 2.80 | 10,000 | 9,200 | 19.68 | 22.32 | 6.52 | 4.35 |
| | B | NPR-4 | 3.3 | 3.60 | 4,000 | 4,000 | 15.69 | 18.37 | 2.68 | 1.84 |
| | A | NPT-4 | 2.4 | 2.7 | - | 9,100 | - | 27.98 | 3.11 | 3.05 |
| | C | NPG-4 | 3.3 | 3.62 | - | 4,000 | - | 18.54 | 2.25 | 1.62 |
| Nero Lake | J | NSS-4 | 3.4 | 3.54 | - | 810 | - | 57.89 | 20.05 | 18.64 |
| | F | NNE-4 | 3.7 | 3.94 | - | 730 | - | 26.71 | 1.46 | 1.62 |
| | G | NDN-4 | 5.3 | 5.81 | - | 780 | - | 62.48 | 7.80 | 7.22 |
| | H | NSC-4 | 6.5 | 7.09 | - | 1,200 | - | 62.78 | 12.56 | 10.40 |
| Beaverlodge Bay | M | BC-0 | 6.85 | 6.80 | - | 500 | - | 77.09 | 11.75 | 17.03 |
| | L | BS-0 | 7.0 | 6.88 | - | 2,400 | - | 27.42 | 2.27 | 1.65 |
| | K | BP-0 | 6.6 | 6.75 | - | 720 | - | 82.87 | 20.36 | 23.06 |
| Eldorado tailings waterlogged | | TM-3 | 7.4 | 7.8 | 1,100 | 270 | - | 16.10 | - | 0.76 |

Note: Determinations 1 and 2 are repeated measurements on the same collected sample, carried out independently by two different persons. pH of distilled water in determination 1 was 6.9 and in 2 was 5.8.

A comparison is made in Figure 1 of heavy metal concentrations in dry tailings, tailings in Nero Lake, and with sediments and organic material in Beaverlodge Bay. As discussed earlier, cobalt, copper and nickel are found in concentration ranges given for soil (Bowen, 1966). Lead, as in Gunnar, appears to be elevated; this also occurs certain locations in Nero Lake tailings, but not in the Beaverlodge Bay sediments and in the periphytic detrital aggregate (P.D.A.). It is notable that the nickel and cobalt concentrations are quite similar along the transect from the tailings out to Beaverlodge Bay. One marked exception is Sample E, which had high organic matter (19% L.O.I., Table 9) which is most likely moss debris. Only in this sample are drastic elevations observed for cobalt and nickel but not for lead and copper. The concentrations of lead and copper along the transect fall off rapidly as the distance to the tailings increases. Sample E is again an exception. It would clearly be desirable to have a comprehensive sampling program, as trends are indicative in Figure 1 of a differential distribution of copper and lead, as compared to nickel and cobalt in the system. The 12 samples of this survey only indicate the validity of the approach.

To facilitate some confidence in the observed trends of the transect, the metal concentrations are compared to results obtained by Ruggles et al., 1979; in Table 10. The concentrations are variable in both surveys. No definite difference in heavy metal concentrations between submerged and dry tailings can be inferred from the observed results. The Beaverlodge Bay sediments are generally lowest for these four metals. The concentrations

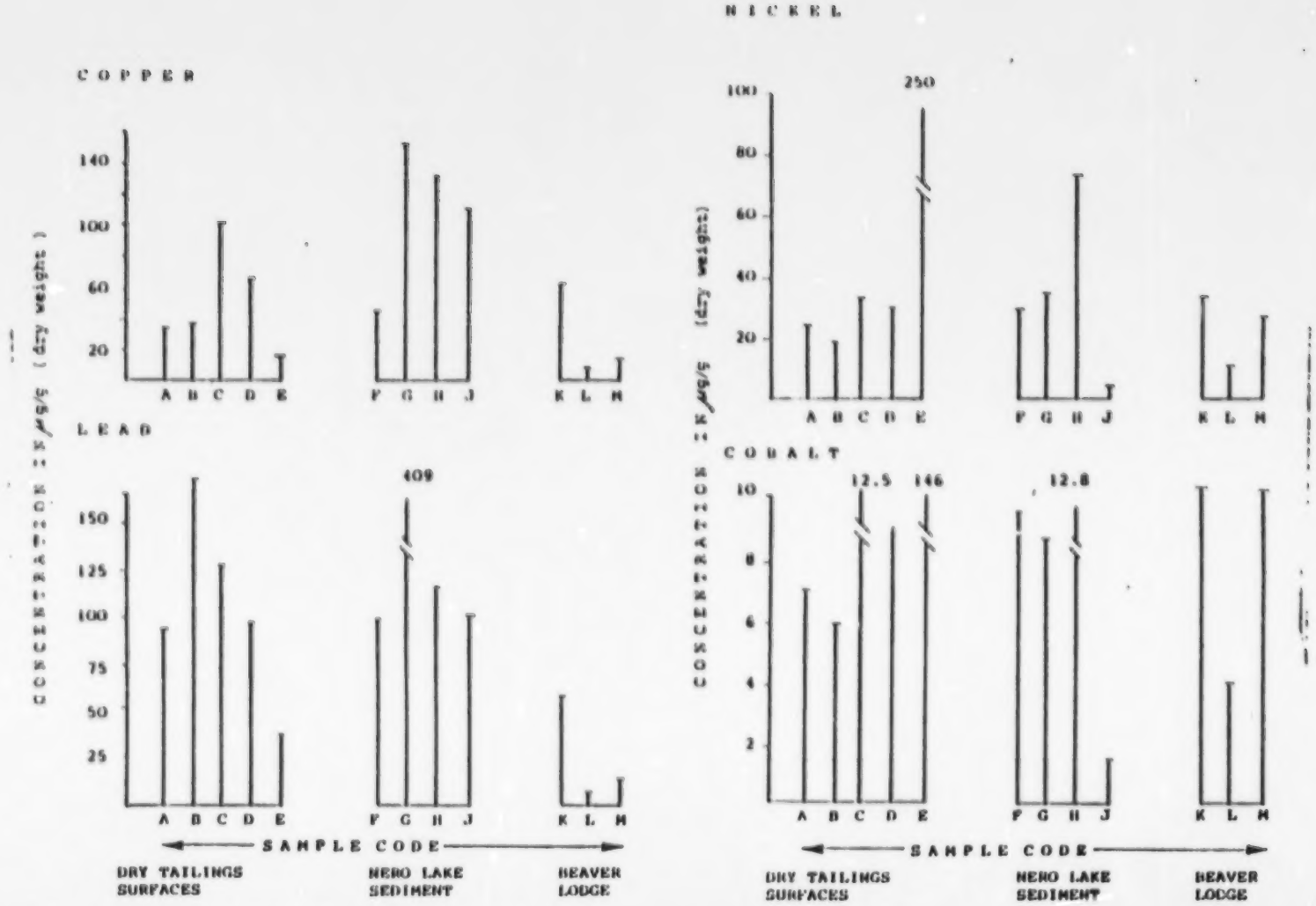



Figure 1. Heavy metal concentrations in substrates: Lorado tailings - Nero Lake - Beaverlodge Bay. (For sampling locations see Map 15, p. 51).

of the P.D.A. and the stonescrape samples are similar to Nero Lake for Ni and Co, but differ for Cu and Pb, from each other and from the Nero Lake sediment concentrations.

Attempting to further delineate differences in sediments of dry and wet tailings, Table 11 summaries results of other elemental concentrations. Again, tailings exposed and submerged are very similar in concentrations determined for Al, Ca, Mg and Mn. Uranium and vanadium are higher in the submerged tailings, but the concentration of uranium in the white organic material (P.D.A.) in Beaverlodge Lake is 4500 ppm.

These uranium concentrations in the P.D.A., in addition to the concentrations of copper and lead, could suggest a selective transport mechanism. A possible explanation is that organic complexes are involved, produced by the moss in Nero Lake. Titayeva (1967) does suggest that uranium is very mobile in surface waters containing small amounts of calcium bicarbonate. Further, he finds that uranium is bound by humic and fulvic acids which are soluable in alkaline substances. The uranium concentrations found in P.D.A. could possibly be due to the same experimentally determined behaviour of uranium by Titayeva (1967).

2.2.2 Water in Nero Lake - Beaverlodge Bay. Five sites in Nero Lake were chosen for water and moss collection. The sites were selected based on a bathymetry chart published by Ruggles et al. (1979). The locations are indicated on Map 14 (numbers 1 to 9). Surface and bottom samples of water were collected at each sampling location (Codes 11-01).

Table 10. Heavy metals in materials associated with Nero Lake

| | Map code | Cu µg/g | Ni µg/g | Pb µg/g | Co µg/g |
|---|---|---|---|---|---|
| Dry tailings | A | 36 | 23.2 | 94 | 6.8 |
| | B | 37 | 20.4 | 177 | 6.2 |
| | C | 100 | 33.6 | 125 | 12.5 |
| | D | 66 | 28.2 | 89 | 8.8 |
| Wet tailings | F | 46 | 28.7 | 97 | 9.5 |
| | G | 156 | 36.0 | 409 | 8.6 |
| | H | 135 | 71.0 | 123 | 12.8 |
| | I | 121 | 152 | 59 | 29.0 |
| Sediment Nero Lake | J | 115 | 1.2 | 109 | 1.5 |
| Sediment Beaverlodge Bay | L | 7 | 9.2 | 5 | 3.7 |
| Shore stonescrape | M | 12 | 27.8 | 12 | 7.0 |
| White organic material (P.D.A.) | K | 66 | 33.4 | 59 | 10.5 |
| Ruggles (1979) | Range | 14-107 | 28-77 | <20-120 | not given |
| wet sediments | $\bar{x}$ | 44 | 55 | 67 | |
| Nero Lake n=12 | sd | 29 | 13 | 49 | |

Table 11. Concentrations of elements in materials associated with Nero Lake

| Sample description | Map code | Number of sampling locations | Al % | Ca % | Mg % | Mn ppm | U ppm | V ppm |
|---|---|---|---|---|---|---|---|---|
| Dry tailings | A-E | n = 4 | 5.5 ±0.7 | 1.0 ±0.4 | 1.4 ±0.3 | 325 ±84 | 90.6 ±15 | 446 ±98 |
| Wet tailings | F-I[1] | n = 4 | 7.3 ±2.6 | 1.0 ±1.1 | 1.3 ±0.5 | 300 ±50 | 697 ±560 | 823 ±395 |
| Sediment Nero | J | n = 1 | 2.3 | 0.2 | 0.3 | 150 | 329 | 2380 |
| Sediment Beaverlodge | L | n = 1 | 5.1 | 0.5 | 0.6 | 320 | 44 | 42 |
| Shore stonescrape | M | n = 1 | 4.4 | 0.4 | 0.5 | 800 | 25 | 42 |
| White organic material | K | n = 1 | 9.3 | 0.7 | 1.2 | 380 | 4483[2] | 152 |

[1]Sample I is moss substrate; no dredge with pure tailings was secured.
[2]Four subsamples were determined separately, average is reported.

The results in Table 12 indicate that Nero Lake was not stratified by mid-August 1980. The concentrations of metals were identical as expected in surface and bottom samples from Nero Lake (Table 13).

Figure 2 represents heavy metal concentrations in water arranged from west to east, i.e. from the pond of the Lorado tailings through Nero Lake out to Beaverlodge Bay. It is apparent that cobalt and nickel decrease by an order of magnitude in Beaverlodge Bay, which is not the case for copper and lead. Note that the concentrations determined in Beaverlodge Bay are mostly detection limits, and in the same ranges as with the control water.

The trends depicted in Figure 2 are quite different from those observed in the tailings and sediments. Nickel and cobalt concentrations in sediments remained reasonably constant along the transect which is not the case for the dissolved concentrations in water. These drop drastically in Beaverlodge Bay. For lead and copper the reverse is the case for the relationship of sediment to dissolved metal concentration. The solubility in the acidic water from Nero Lake should be similar for all metals. It appears therefore, that the form of lead and copper in the tailings is bound in such a way as to render it less soluble than nickel and cobalt.

The conductivity of the water of 2300 µmhos/cm and the observations of metal concentrations indicate the complexity of the Nero Lake water chemistry. Given the small number of samples, these deductions are made tentatively.

Table 12. Stratification of Nero Lake in August 1980.

| | Map code | Analysis sample code | pH | Conductivity µ mhos/cm | Dissolved oxygen ppm | Temperature °C |
|---|---|---|---|---|---|---|
| Beach east end surface | 6 | NSS-11 | 3.5 | 2200 | sat. | 18 |
| Beach west end surface | 2 | NNE-11 | 3.5 | 2300 | sat. | 17 |
| Deep east end surface | 3 | NDS-11 | 3.2 | 2250 | 8.9 | 19 |
| depth (9.5 m) bottom | | NDS-01 | 3.2 | 2250 | 7.2 | 18 |
| Deep west end surface | 5 | NDN-11 | 3.4 | 2300 | 8.4 | |
| depth (9 m) bottom | | NDN-01 | 3.5 | 2100 | 7.8 | 17 |
| Shallow centre surface | 4 | NSC-11 | 3.5 | 2300 | 9.2 | 19 |
| depth (3 m) bottom | | NSC-01 | 4.7 | 2100 | 3.1* | 18 |

Note: *measured in sediment; sat. = saturated

Table 13. Water characteristics and, heavy metal concentrations in Nero Lake.

| Site | Map code | Analysis code | pH | Conductivity µmhos/cm | Copper mg/l | Nickel mg/l | Cobalt mg/l | Lead mg/l |
|---|---|---|---|---|---|---|---|---|
| NERO LAKE: | | | | | | | | |
| East end, shallow beach | 6 | NSS-11 | 3.5 | 2,200 | 0.046 | 0.252 | 0.093 | 0.020 |
| West end, east tailings beach | 2 | NNE-11 | 3.5 | 2,300 | 0.023 | 0.267 | 0.093 | 0.047 |
| Deep west | 3 | NDN-11 | 3.4 | 2,300 | 0.018 | 0.257 | 0.093 | 0.030 |
| | | NDN-01 | 3.5 | 2,100 | 0.040 | 0.262 | 0.098 | 0.055 |
| Deep east | 5 | NDS-11 | 3.2 | 2,250 | 0.046 | 0.272 | 0.093 | 0.025 |
| | | NDS-01 | 3.2 | 2.250 | 0.057 | 0.267 | 0.093 | 0.040 |
| Shallow centre | 4 | NSC-11 | 3.5 | 2.300 | 0.047 | 0.287 | 0.102 | 0.025 |
| | | NSC-01 | 4.7 | 2,100 | 0.040 | 0.279 | 0.102 | 0.047 |
| Nero Lake: mean concentrations | | | | | $\bar{x}$:0.039<br>sd:0.013 | 0.267<br>0.011 | 0.096<br>0.004 | 0.036<br>0.013 |
| Surface tailings pond | 1 | NPT-11 | 2.3 | 12,000 | 0.314 | 9.14 | 4.13 | - |
| Invasion Bay 15 m out moss site | D | MIN-11 | 3.1 | 2.200 | 0.040 | 0.304 | 0.088 | - |
| Nero Swamp, Control | 8 | CNS-11 | 7.1 | 280 | - | - | - | - |
| EPA (#2-476 E) | | our analysis | | | 0.425 | | 0.347 | 0.405 |
| Water (#3-476 E) | | our analysis | | | | 0.098 | | |
| Expected EPA value | | | | | 0.348 | 0.096 | 0.348 | 0.383 |
| % yield of analysis | | | | | 122.0 | 102.0 | 99.7 | 106.0 |

Legend: -11 = surface sample; -01 = bottom sample; - = not detectable.

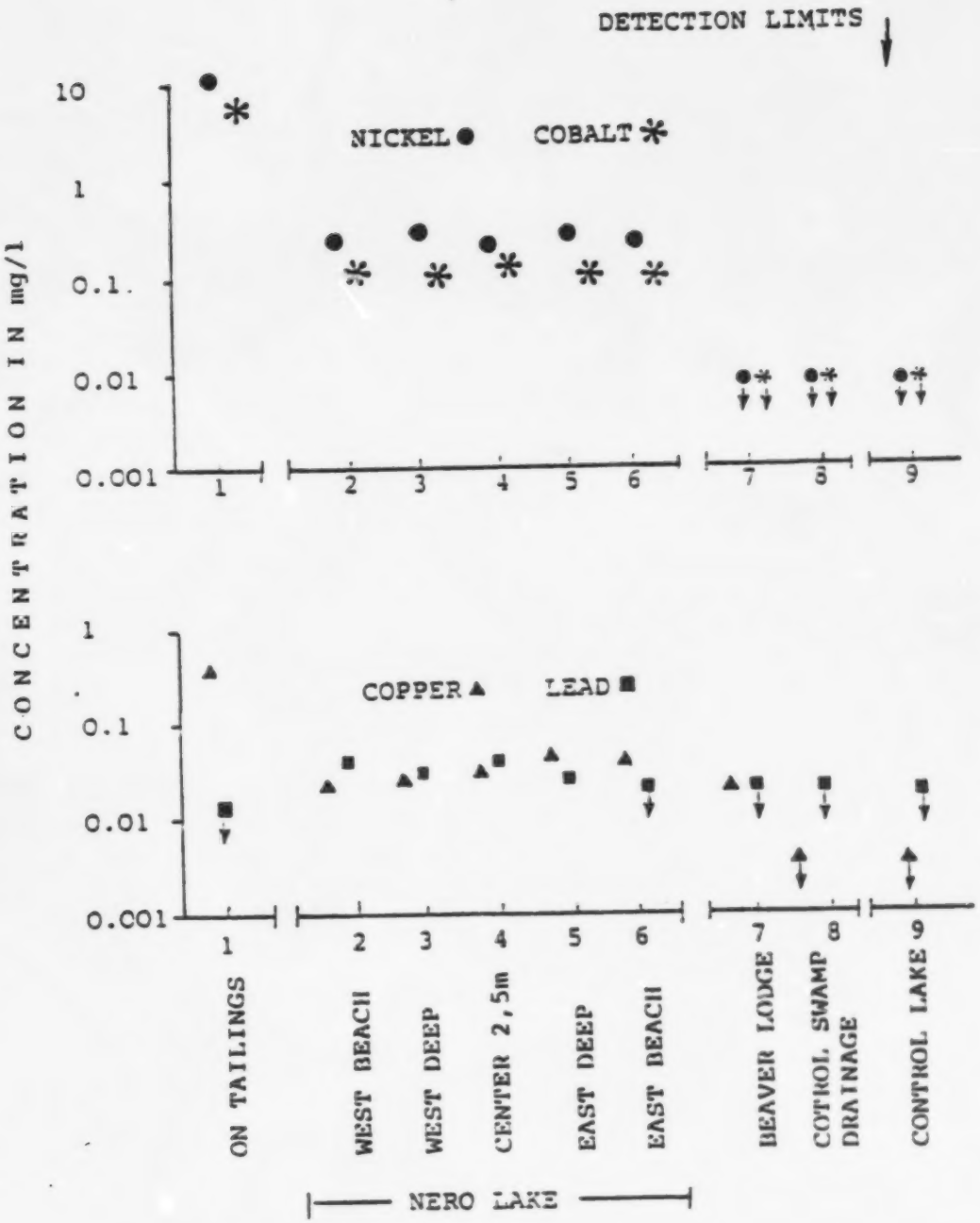



Figure 2. Heavey metal concentrations in water on Lorago tailings, in Nero Lake, in Beaverlodge Bay and control waters. (For sampling locations see Map 14, page 45)

A water sampling program in Nero Lake and Beaverlodge Bay was carried out in 1976 and 1978 (Ruggles et al (1979). These data were compared to the reported water characteristics from the present survey. The results in Table 14 indicate that for the elements which are in common for all three surveys the concentrations are in good agreement. This could suggest that the water quality in Nero Lake has not changed for at least the past four years. Since the tailings have been in Nero Lake for two decades, it is reasonable to suggest that the observed state of the system has approached some equilibrium.

## 2.3 The moss in Nero Lake

2.3.1 Moss growth and chemical analysis. The sampling locations of mosses are given together with water sample locations on Map 14, indicated by the letters A to M. The protected, shallow bays have shores which are invaded by moss, such as a bay named "Invasion Bay" (Map 14: locations A-D; Plate 18). The moss was identified as Leptodyctium riparium (Hedw.) Warnst. All samples from the shore sites A, B and C to the 15 m deep site D, consisted of the same species exhibiting slightly different morphological forms. Rocky, shallow, and gravel covered shores were free of moss.

L. riparium was also located in a control lake slightly to the north of the old Lorado Mine road (59° 30' 30"; 108° 43'0"). The moss from the control lake is somewhat drier than that from "Invasion Bay" (Plate 24). The pH of 3.5 at the control site is the same as the pH of Nero Lake exactly. A further noteworthy observation is that the conductivity of the water was 1200 µmhos/cm which is lower than the water in Nero Lake.

Table 14. Comparison of water determinations from 1976 to 1980 in Nero Lake and Beaverlodge Bay

| Elements determined | 1976[1] | | 1978[1] | | 1980 | |
|---|---|---|---|---|---|---|
| | Nero Lake | Beaverlodge Bay | Nero Lake | Beaverlodge Bay | Nero Lake | Beaverlodge Bay |
| Cu | 0.052 | 0.018 | 0.03 | ≤0.02 | 0.038 | 0.02 |
| Ni | 0.35 | 0.09 | 0.41 | 0.04 | 0.270 | ≤0.008 |
| Co | - | - | - | - | 0.090 | <0.007 |
| Pb | ≤0.1 | 0.1 | 0.047 | ≤0.005 | 0.020 | <0.02 |
| Ca | - | - | 200 | 17 | 191 | 15 |
| Al | - | - | - | - | 36 | 0.06 |
| U | 0.85 | 0.24 | 0.74 | 0.23 | 0.70 | 0.21 |
| V | 0.7 | ≤0.1 | - | - | <0.015 | ≤0.002 |
| Na | 47 | 44 | 49 | 24 | 50 | 26 |
| Mn | - | - | - | - | 10 | 1.0 |
| Mg | - | - | 125 | 4 | 131 | 5.6 |
| pH | 3.5 | 3.8* | 3.5 | 7.5 | 3.5 | 7.7 |
| Conductivity μ mhos/cm | 2200 | 2000* | 2000 | 200 | 2200 | 220 |

Note: Concentrations given in mg/l

*Likely water sampled close to Nero Lake discharge

[1]Source: Ruggles *et al.* (1979)

Table 15 summarizes the results of the moss analysis. The totally submerged moss specimens (lake samples G-F) appear consistently higher in concentrations of Cu, Ni, Co, Pb, and U. The elements Al, Ca, Mg, Mn and V vary in concentrations and are closer to the ranges observed in the Invasion Bay collection (samples A-D). These elements, in contrast to Cu, Ni, Co and Pb appear in relatively similar concentrations to those of the mosses collected from Beaverlodge Lake and from the control lake. Unfortunately, the variations are too large, and the sample size too small, to allow a valid comparison to the water or tailings concentrations. In general, all lake moss samples are somewhat higher in concentrations of copper and lead, but are similar in concentrations for nickel and cobalt when compared to tailings. This reflects somewhat the trends observed for the tailings-sediments, and may be connected to the dissolved concentrations of elements observed in the water. It is suggested, tentatively, that L. riparium selectively binds lead and copper over nickel and cobalt.

In general Sphagnum cuspidatum collected on the berm between Nero Lake and Beaverlodge Bay, is closer in its elemental concentrations to the samples from Invasion Bay, than to the deep collections of L. riparium.

In Table 16, the data are considered from a different viewpoint attempting to clarify tailings-moss relationship. The tailings concentrations determined were differentiated with respect to the contact with the moss, i.e. the material washed directly from the moss, and the tailings dredged in the same location. Table 16 gives elemental ratios (moss over tailings concentration) for

Table 15. Element concentrations in *L. riparium* in Nero Lake and control sites in µg/g dry weight

| | Map code | Cu* | Co* | Ni* | Pb* | U | Al | Ca | Mg | Mn | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| "Invasion Bay" shore | A | 27 | 2.3 | 8 | 29 | 240 | 2320 | 1450 | 1460 | 50 | 112 |
| | B | 21 | 1.4 | 10 | 30 | 147 | 1070 | 1650 | 720 | 44 | 10 |
| | C | 38 | 1.2 | 41 | 29 | 644 | 4900 | 3190 | ≤3700 | 56 | 522 |
| | D | 68 | ≤0.5 | ≤0.5 | 24 | 182 | 5096 | 1050 | ≤3170 | 54 | 70 |
| Lake samples | G | 125 | 4.6 | 17 | 205 | 1070 | 9020 | 6560 | ≤1860 | 91 | 850 |
| | I | 126 | 4.0 | 27 | 198 | 171 | 1170 | 1250 | 1180 | 36 | 21 |
| | H | 234 | 2.4 | 12 | 102 | 820 | 940 | 2280 | 2450 | 48 | 27 |
| | F | 170 | 3.6 | 14 | 83 | 184 | 5610 | 1370 | 1182 | 64 | 197 |
| Berm discharge *S. cuspidatum* | K | 50 | 1.4 | 13 | 44 | 622 | 8660 | 3290 | ≤2513 | 51 | 92 |
| Lorado mine discharge | L | 10 | ≤0.6 | 2.5 | ≤1.2 | 15 | 1140 | 365 | 569 | 15 | 68 |
| Nero shore tailings free | J | 40 | 2.3 | 7.2 | 37 | 247 | 1620 | 2940 | 1331 | 36 | 75 |
| Control moss | $M_1$ | 10 | 0.7 | 7 | 7 | 2 | 1470 | 1740 | 1395 | 33 | 3 |
| | $M_2$ | 12 | ≤0.4 | 9 | 28 | 4 | 2230 | 950 | 753 | 30 | 30 |
| Mean concentration Nero water µg/l | | 0.039 ±0.013 | 0.267 ±0.011 | 0.096 ±0.004 | 0.039 ±0.013 | 0.69 ±0.03 | 36 ±1.6 | 192 ±9.3 | 131 ±10 | 10 0.5 | ≤0.015 |

* Determined by atomic absorbtion, other elements determined by Neutron activation

Table 16. Elemental ratios of *L. riparium* over substrates in Nero Lake

| | Map code | Cu | Ni | Pb | Co | U | Al | Ca | Mg | Mn | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Moss/ immediately associated substrate | G | 0.72 | 0.40 | 0.56 | 0.61 | 1.7 | 0.12 | 1.3 | 0.2 | 0.33 | 1.1 |
| | H | 4.70 | 0.90 | 0.66 | 0.39 | 1.4 | 0.03 | 1.6 | 0.6 | 0.17 | 0.02 |
| | I | 1.04 | 0.18 | 3.36 | 0.31 | 0.2 | 0.03 | 0.14 | 0.16 | 0.13 | 0.06 |
| | J | 0.14 | >2.1 | 0.35 | 0.30 | 0.6 | 0.09 | 1.0 | 0.3 | 0.27 | 0.2 |
| Moss/substrate sampled from same dredge | G | 0.8 | 0.46 | 0.5 | 0.5 | 0.9 | 0.08 | 2.3 | ≤0.2 | 0.3 | 0.7 |
| | H | 1.7 | 0.17 | 0.8 | 0.18 | 0.9 | 0.02 | 0.09 | 0.3 | 0.1 | 0.03 |
| | J | 0.3 | <6.0 | 0.3 | 1.5 | 0.7 | 0.07 | 1.26 | 0.4 | 0.2 | 0.03 |
| Bryophyte ratios after Shacklette (1965) | | >400 | 33 | 200 | >20 | n.d. | 45 | 100 | 150 | 100 | 7 |
| Absolute concentration µg/g Moss Ash weight Shacklette (1965) | | 204 | 83 | 1860 | 32 | n.d. | 42000 | 204 | 19700 | 3058 | 71 |

each of the combinations. The ratios for all elements are effectively the same for both types washed from the moss and obtained in separate dredges. The ratios in general are close to unity for uranium, and 0.1 for aluminum. The other elemental ratios vary greatly; some moss samples indicate slight exclusion, others slight accumulation of elements. In effect, the moss concentrations are somewhat lower than those of the substrate, but generally very close to the tailings concentrations.

Considering uptake ratios for bryophytes by Shacklette (1965), the ratios observed in Nero Lake are low when calculated on substrate concentrations. However, if the ratios were based on dissolved concentrations of elements in the water they would in many cases exceed the reported values of Shacklette (1965). As accumulation ratios are likely more realistically based on dissolved material for an aquatic bryophyte, it is reasonable to suggest that L. riparium absorbs considerable amounts of elements released from the tailings. This conjecture is tentative and needs confirmation, especially as the absolute concentrations in moss collected in control locations (L and $M_1$ and $M_2$) are not considerably lower than the Invasion Bay collection (samples A to D). The absolute concentrations given by Shacklette (1965) based on ash weight are similar for some elements, if the difference of dry weight/ash weight is considered. Some elements such as aluminum and magnesium differ. In general, it does not appear that elemental concentrations in L. riparium in Nero Lake, with the exception of uranium, are unusual for bryophytes. Shacklette (1965) did not detect any uranium in bryophytes; however, his collection of samples included only a few aquatic

species.

2.3.2 Moss aquaria and experiments

Culture aquaria

Samples of L. riparium, from all the sites (Map 2; A-J), were kept in an aerated aquarium in the laboratory. The aquaria were monitored daily for pH and conductivity changes. The main objective was to determine whether cultures of L. riparium could be maintained in the laboratory for future experiments.

It appears from these preliminary aquaria experiments that moss cultures can be maintained in reasonably good conditions for several months. Some further observations can be made after a period of five months of culturing. The best growth was achieved in the aquaria with the control moss. If the pH in the Nero Lake tanks drops below 2.5, microbial, fungal and algal growth became prominent. The L. riparium from the deep locations in Nero Lake are still alive; however, they are considerably more fragile than the control moss. The collections from the shallow locations did not survive in the aquaria as long as did the collections from the control locations.

Experiments

An attempt was made to develop a method to determine growth rate and growth conditions of L. riparium in Nero Lake. Unfiltered Nero Lake water and tailings extracts (5 g of Lorado tailings in 1:1 (v:w) dist. water) alone, and

the same water supplemented with a nutrient solution (BBM, modified) were used to submerge strands of moss. After the first 12 days of the experiment most moss strands had bleached or were infected by a mold. Only some strands in the Nero Lake water and some in the tailings extract survived and these were mainly control moss strands.

Subsequently, clumps of L. riparium were added to the solution from the aquaria. It appeared, after consideration of other factors such as pH and conductivity, that the mechanical handling might be the problem. After three weeks it was found that all moss clumps were surviving and considerable growth was noted, especially in the Nero Lake water and the tailings extract. The composition of the solutions and some results of the monitoring of pH is given in Appendix 3.

## 2.4 Lorado - Nero Lake - Beaverlodge Bay - Discussion

The acidic water from Nero Lake seeping into Beaverlodge Bay appears to equilibrate rapidly with water in the Bay (Table 5). At least, this was observed at the end of the season, in August, when the water flow from Nero Lake to Beaverlodge Bay was relatively small. Changes in the observed concentrations of cobalt and nickel may be detectable since both elements are elevated in Nero Lake in the earlier part of the year.

It can be expected that metals in the acidic waters of Nero Lake are soluble, and one would anticipate a drop in concentration for all four metals in Beaverlodge Bay. This is observed for nickel and cobalt (Figure 2). Copper and lead dissolved in water do not follow the expected trend. It is noteworthy that copper and lead concentrations are higher in the tailings than in the sediments of Beaverlodge Bay. The concentrations in the water are not particularly high for copper in Nero Lake. Bowen (1966) gives a value of 0.01 ppm as background in fresh water. Lead concentrations in the water are elevated approximately ten times when compared to Bowen (1966) who quotes 0.005 ppm of lead in fresh water. Control water samples from the area are also in this concentration range (Table 2, Section 1), as nearly all water samples have a concentration below the detection limit. (Detection limits are given in Table 2, Appendix B).

The berm between Nero Lake and Beaverlodge Bay appears to be saturated with Nero Lake water (Table 4). The transport of elements from Nero Lake to Beaverlodge Bay

appears to be varied for different elements. This is especially the case for uranium, which is concentrated on the Beaverlodge Bay side of the berm in the periphytic detrital aggregate (Table 7). However, these observations could also be the result of differences in solubility, binding or selective accumulation by L. riparium in Nero Lake as discussed earlier. Based on the few samples taken, it is not possible to make any conclusions, other than to recognize that the system is very complex and needs further study.

In general, the condition of Nero Lake and the effects on Beaverlodge Bay do not appear to have changed as the parameters sampled indicate when compared to previous surveys in 1976, 1978 and 1980 (Table 3).

When elemental concentrations in submerged and exposed tailings were compared to determine possible leaching from the exposed tailings to Nero Lake, the results did not indicate differences in concentrations present. The exposed tailings were very acidic, a depletion of the surface layers in some elemental concentrations could have occurred during the 16 years of abandonment. The water in a small pond on the exposed tailings is significantly higher in copper, nickel and cobalt, but no lead was detected (Table 2). This may be an analytical error. On the other hand, if correct, it would add to the complex behaviour of lead, discussed earlier.

One suggestion to ameliorate the Lorado tailings, was to dispose of the exposed tailings into Nero Lake which could prevent further acid generation. Bruce (1977)

found that the Lorado exposed tailings were acid generating.

Considering the findings discussed earlier, this solution appears certainly undesirable given the present lack of understanding of the Nero Lake-Beaverlodge interactions. To connect the existence of L. riparium to the system, the following considerations can be presented. The fragility of L. riparium is indicated by the preliminary experiments with the moss. The conditions in Nero Lake appear to be so specialized that a habitat barely suitable for L. riparium is created. The same moss species were found, together with Sphagnum cuspidatum, in tailings ponds in Elliot Lake, however, the cover was not as extensive as in Nero Lake. The existence of this moss cover, at the bottom of Nero Lake will likely prevent further oxidation of the sulphur. As the Lake did not appear to be stratified, oxygen could reach the tailings and further acidification of Nero Lake water could be expected, in the absence of the lower part of the moss cover, which is anoxic. An addition of more tailings to Nero Lake is likely to affect the moss adversely. This could in turn result in further depression of the pH. Surface waters on the tailings appeared clearly more acidic (see Table 2).

A second important consideration is the origin and nature of the water at present in Nero Lake. It is suggested that L. riparium is maintaining the lake at pH 3.5. The pH in the control location of L. riparium was 3.5, and the conductivity was elevated. The water in Nero Lake, given the presence of the L. riparium and in the surrounding bays, is likely rich in humic acids, which will add $H^+$ ions to the system. In addition, the control moss

site had a low pH factor which further indicates that the pH in Nero Lake may not be a result of tailing deposits alone.

It is evident from this survey that further studies are needed to understand the process which occur in Nero Lake. This is necessary before any changes are made to the present situation, because of the unpredicatable effect this may have on Beaverlodge Bay.

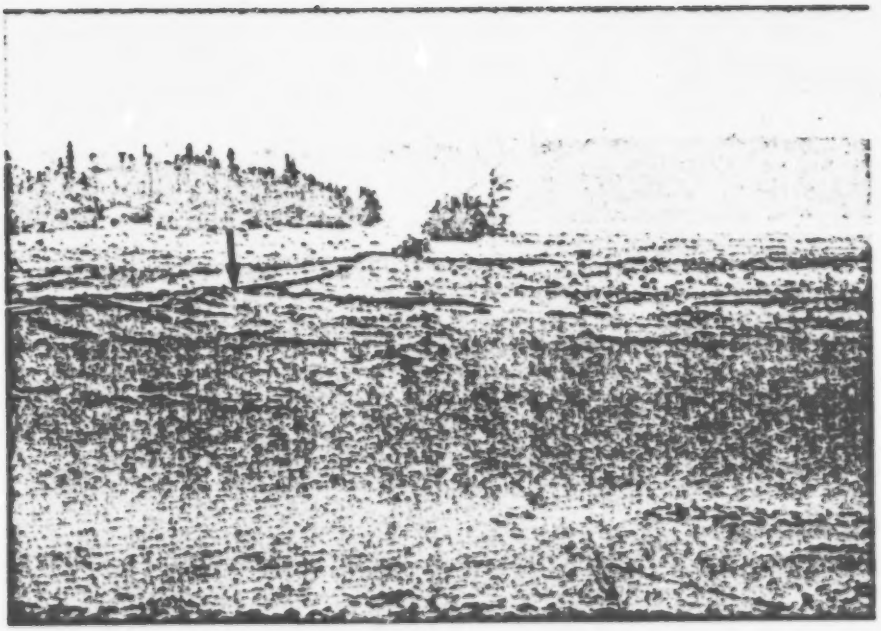


Plate 1: Gunnar, section of windblown tailings with buried slurry pipe.

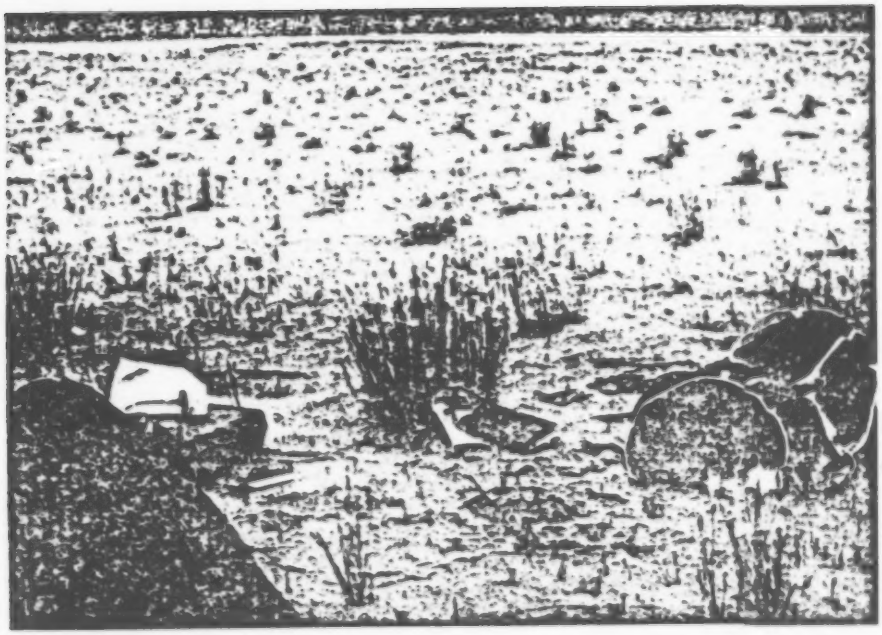


Plate 2: A typical grass hummock sample secured for analysis on Gunnar tailings.

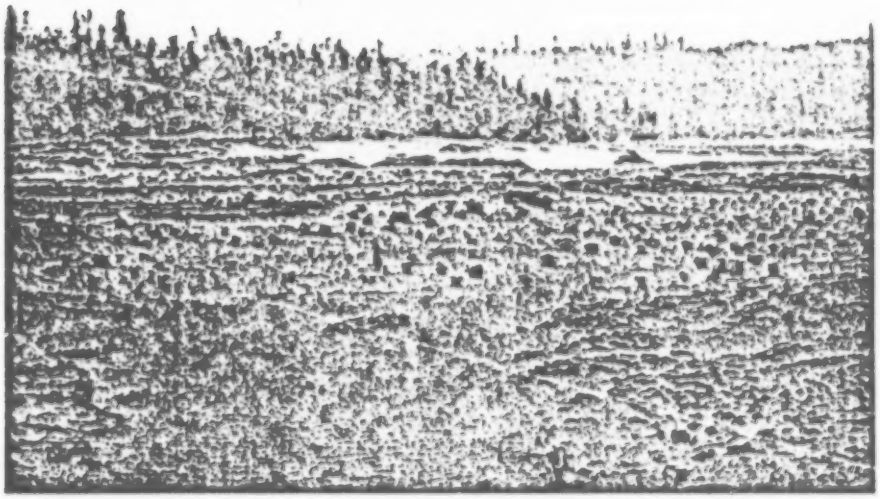


Plate 3: The edges between the windblown section and the grass belt on Gunnar..

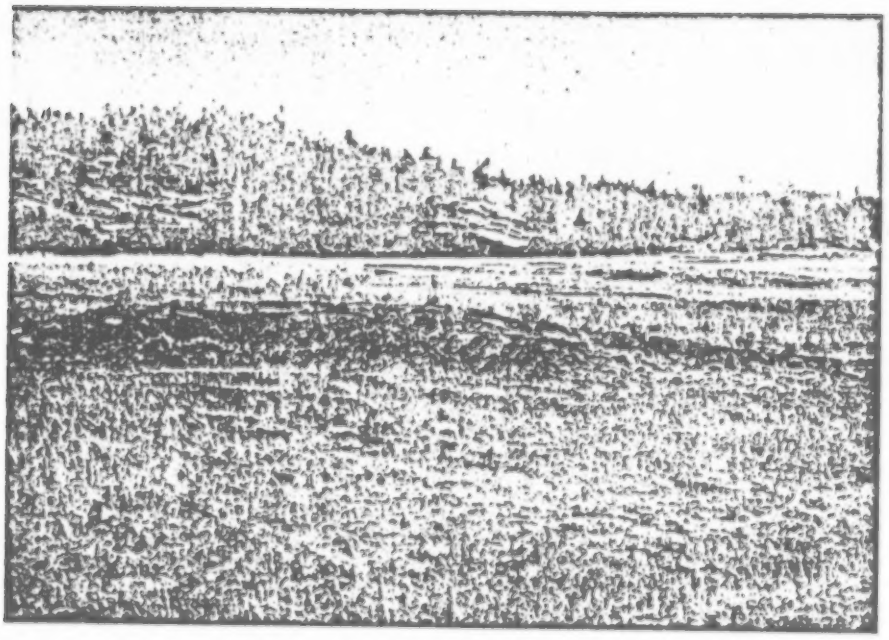


Plate 4: A typical section of the grass belt on Gunnar tailings.

Table 5: The vegetation cover on Gunnar "central" tailings. On the edges of the opening, shrubs invade the site.

Plate 6: The grass belt bordering the windblown section, with white encrustment in the foreground.

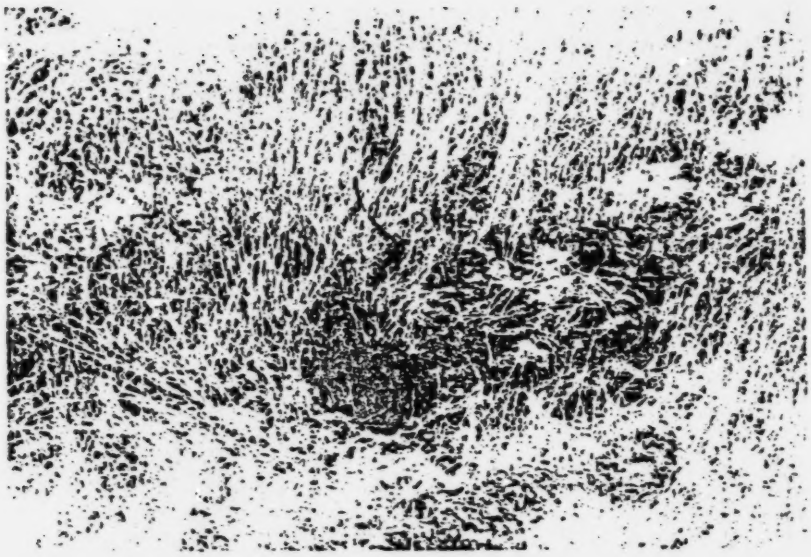


Plate 7: The excavated pit in the grass belt, in close vicinity to the encrusted area.

Plate 8: Roots penetrate approximately 10 - 20 cm into the tailings.

Plate: 9 Reduced growth of grasses in the islands of encrustment.

Plate 10: An area of tree stumps, missing the tree crowns, possibly related to past water level?

Plate 11: Dense growth of sedges are found in the first widening on the way from Gunnar tailings to Langely Bay.

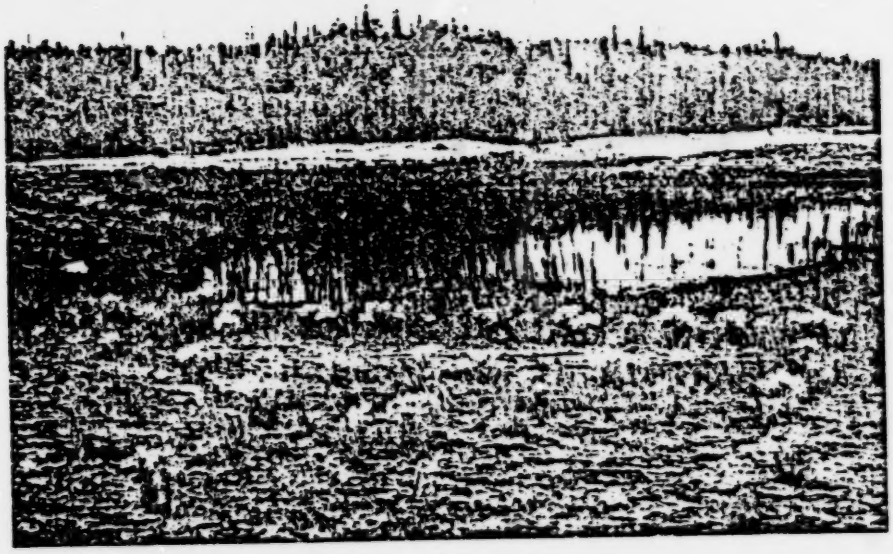


Plate 12: The water-moist section of Gunnar Main tailings with *Typha sp.* growth.

Plate 13: Lorado tailings viewed from the road. Small ponds are remainders of the overflowed lake. Two grass hummocks are the only vegetation on the site (arrow).

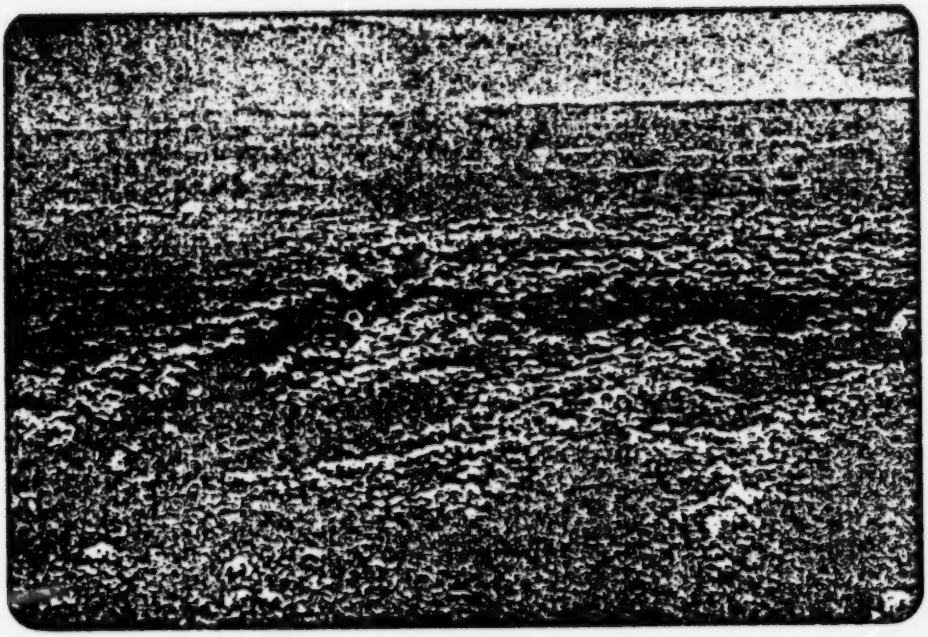


Plate 14: Some areas on Lorado tailings are covered with white crystals, likely magnesium sulfate discharged from the $U_3O_8$ extraction process.

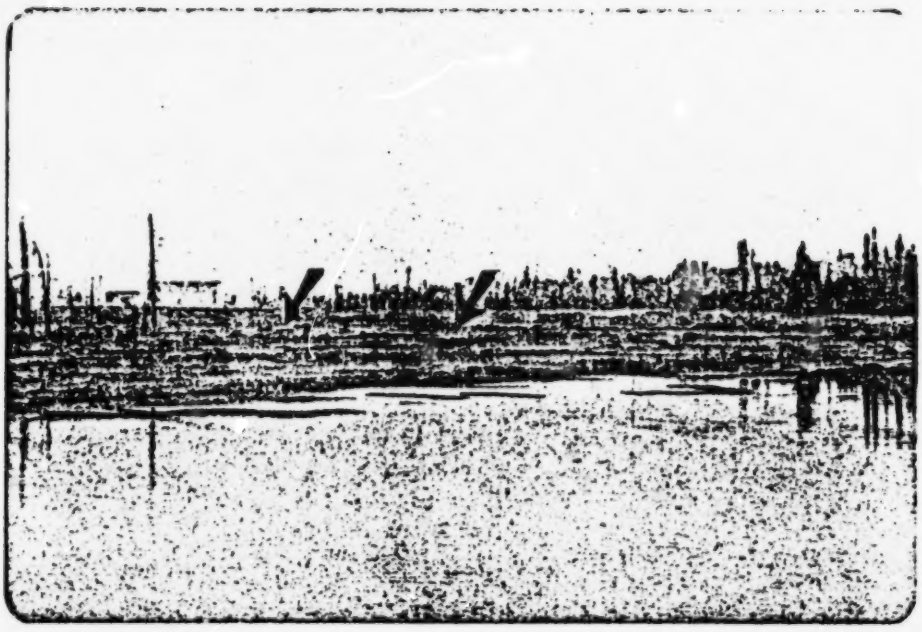


Plate 15: The eastern tailings beach of Lorado tailings. Rows of dead moss in the foreground on the beach. Extensive white areas are located in the centre of the beach (arrow).

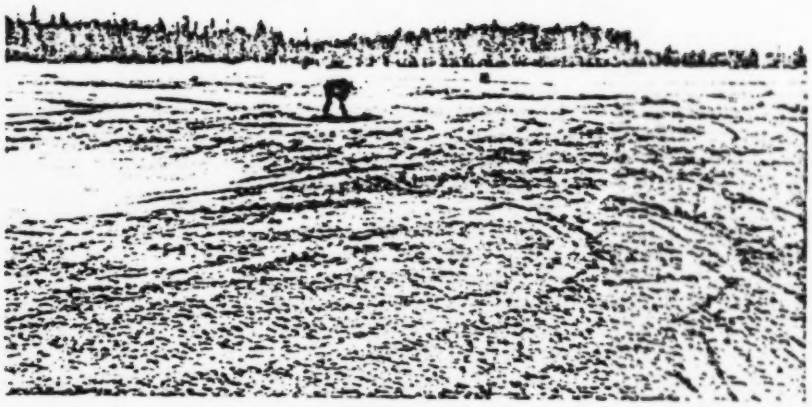


Plate 16: Lorado tailings with patterns of extensive use by vehicles.

Plate 17: The typical shore vegetation on Nero Lake is a black spruce swamp. The trees indicate drastic changes in water levels.

Plate 18: Moss growth at the shores of Nero Lake. This site is referred to as "Invasion Bay", sampling location A, B and C on Map 1.

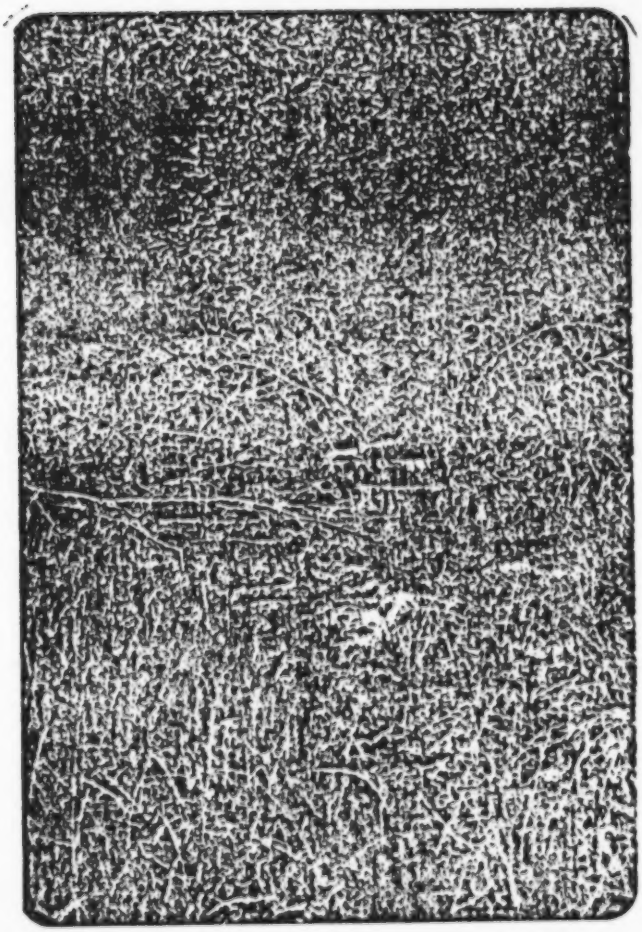


Plate 19: The berm between Nero Lake and Beaverlodge Bay is densely overgrown.

Plate 20: The old culvert connecting Nero Lake to Beaverlodge. The water in August clearly leaves through the ground, as the culvert is dry.

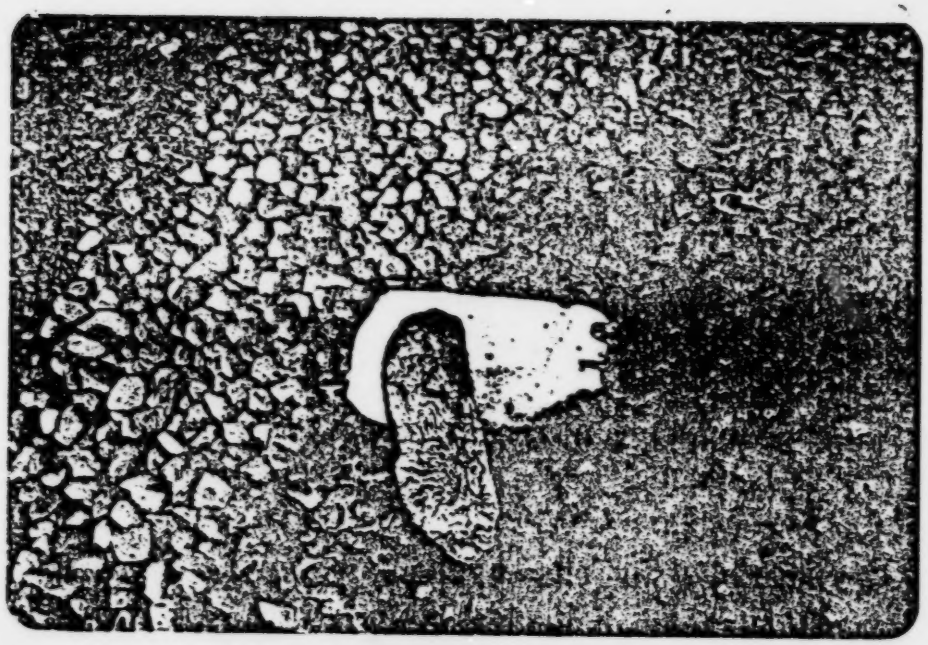


Plate 21: A wet and a dry stone on the shores of Beaverlodge Bay, close to the Nero Lake discharge. The colouration occurs as the surface dries.

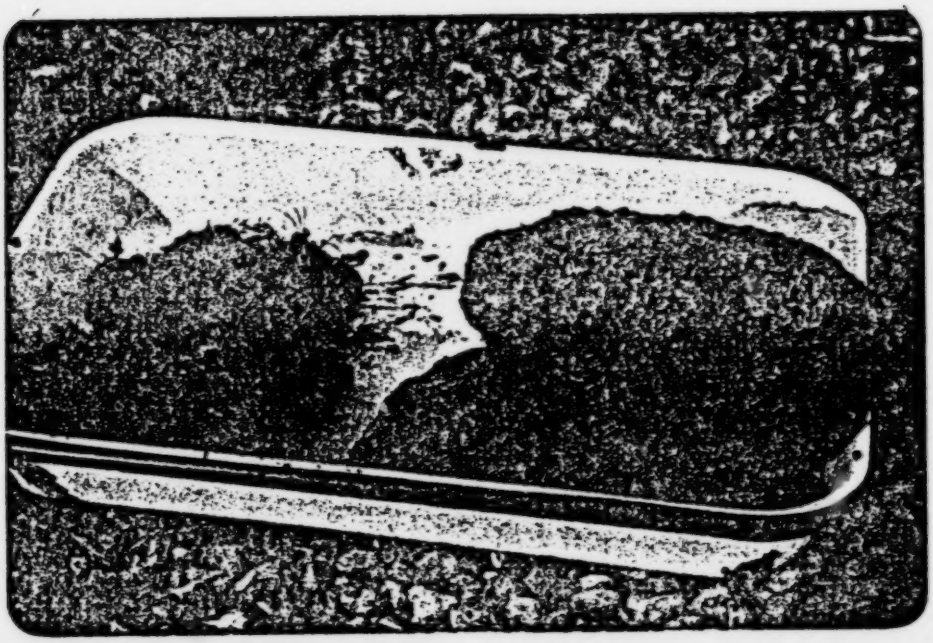


Plate 22: The white cover in Beaverlodge Bay on stones and vegetation.

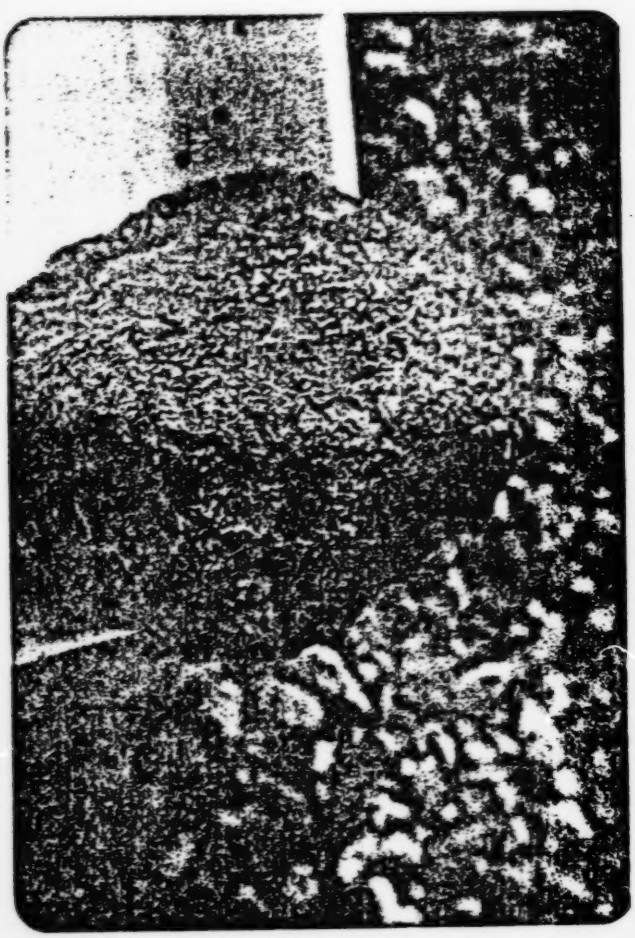


Plate 23: The organic nature of the mat is apparent.
Microscopic investigation revealed extensive growth of filamentous blue-green algae.

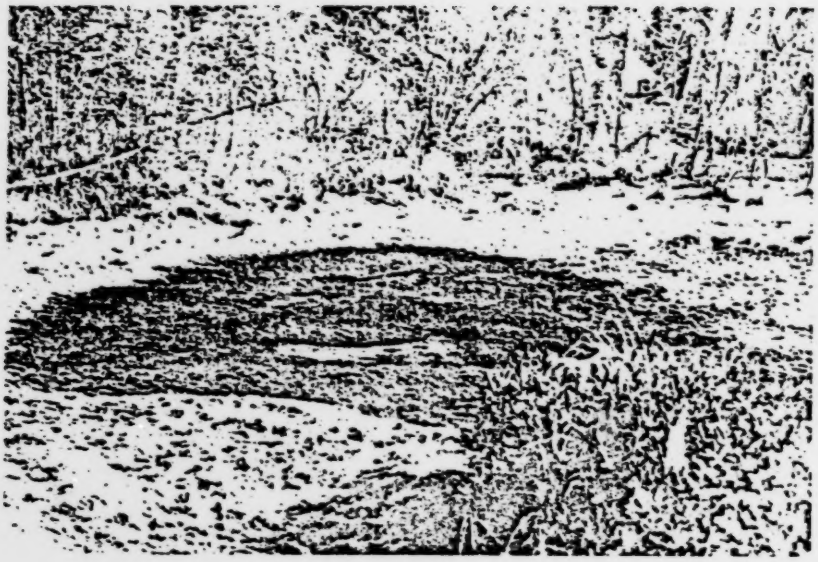


Plate 24: Moss growth at the shores of the Control Lake (59° 30' 30", 108° 43'). The bay is completely water-logged, which makes access to document the similarity to "Invasion Bay" impossible.

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APPENDIX A

Terms of References

1. The Contractor under the direction of Ms. Margarete Kalin agrees to:

(a) Collect and identify existing aquatic macrophyte flora in Nero Lake and terrestrial flora on tailings deposits near the dormant Gunnar uranium mill in northern Saskatchewan;

(b) Analyse approximately 15 selected samples of flora from the two sites for Ra 226, Pb 210, and U-natural. Review and interpret the analytical results and present them in the form of a report;

(c) Collect and analyse for metals (Pb, Ni, Cu, Co, V, Ca, Ba, Mn) approximately 60 samples of aquatic or terrestrial flora, soil (tailings), and water from the two areas of study for the purpose of determining the concentration factors for each of the metals by various species of flora;

(d) Determine for each sample collection, organic content (L.O.I.), pH, moisture content and conductivity on the terrestrial site near Gunnar mill. For the aquatic site samples (Nero Lake) determine pH, temperature, conductivity, dissolved oxygen, and alkalinity;

(e) Make possible recommendations regarding the condition under which the invasion of the two tailings deposits by indigenous flora may be enhanced;

(f) Propose measures/studies that would be necessary to confirm the recommendations of the final report.

APPENDIX B

Detailed Methods

1. (a) Water sample collection. Water was sampled in shallow water by submerging the sampling bottle directly; in deeper waters, the sampling was carried out with a Van-Dorne sampler. Determination of pH was made with a Sargent & Welsch, Model PBX with glass combination electrode S 300-73-15 and conductivity with a YSI, model 33, S.C.T. For deep sampling locations, temperature and oxygen profiles were determined using a YSI, Model 4. R.C. oxygen-meter with a combined oxygen and temperature probe. Light penetration was determined by Secchi disk.

(b) Moss and tailings collection. An Eckman dredge was used to collect the moss. The contents of the dredge were transferred to a dish where pH and conductivity was measured. Additional dredges were made for tailings or sediment collection and for the above measurements.

(c) Grass collection. Grass hummocks were sampled for analysis. The hummocks were freed from all seeds which were collected in a plastic bag. The plants were excavated and the clump was placed on a cloth sheet. The tailings immediately around the roots were thus separated from surface tailings and secured for analysis. The stems and leaves were cut and secured in a plastic bag. Similarly roots and

tailings were separated and transferred to plastic bags. The same procedure was followed for all vegetation, which was sampled for chemical analysis. Locations for the grasses collected for analysis are indicated on Map 3. Typha latifolia was collected in locations T1 and T2 where small ponds formed on the tailings.

2. Sample storage and transportation

(a) Vegetation and tailings. Dry tailings samples were stored in the hotel room as is. The plastic bags of the vegetation were opened to prevent possible condensation.

The moist or wet samples (T. latifolia and some tailings) were stored in a cooler which was supplied as often as possible with ice.

Moss samples were kept in coolers with ice and shipped immediately to the laboratory where aquaria were established so the moss could be maintained for experiments.

(b) Water samples. The water samples were filtered through 0.45 micron sartorius filter paper within 6-8 hours from the time of collection, and acidified with concentrated nitric acid. Samples were shipped with ice by air express to Toronto, where tailings and vegetation were frozen immediately. The water samples were kept cool.

3. Sample preparation

(a) Vegetation. All the grass samples were wrapped in qauze and washed under tap water with some pressure. This washing was followed by several rinses in distilled water with detergent (Palmolive) and three rinses with distilled water. Spot samples were taken of the rinse water for analysis of heavy metals. The samples were cut and mixed in a Waring Commerical blender. The materials were dried at 78°C in a drying oven (Despatch, Model LDB1-69).

The substrates to which the moss was attached were washed from the moss first and then secured together with the washing water, to be dried. The moss was then washed further in distilled water (pH 5.7). Several rinses in distilled water were made, some with the addition of detergent (Palmolive). The washed moss was inspected with a microscope for retention of particles before drying.

The T. latifolia was separated into seeds, stems, leaves, roots and rhizomes. The parts were washed first with tap water under presssure, followed by rinses with detergent and distilled water. Roots and rhizomes were scrubbed with a brush and then washed as above.

The different parts were homogenized in a commercial blender. The homogenized sample was frozen at - 50 C. To obtain a dry weight of 2.00 g, several sub-samples were used or in some cases the entire sample was dried.

(b) Tailings - Preparation of entire samples. The bags were completely emptied and the contents hand (wearing gloves) sorted for stones and other larger objects; a mixing was also achieved in this way. The samples were described recording texture, colour and particle type content. This process was carried out twice, by two different workers independently.

(c) Preparation of individual samples - Moisture content and loss on ignition. One sub-sample of approximately 3 g was dried at 78°C in a drying oven. Approximately 1 g was removed after drying point was reached to use for atomic absorption analysis and 0.5 g was placed in neutron activation capsules. The remainder was heated to a temperature of 450°C in a muffle oven for four hours and after cooling weighted again. This procedure was repeated with a second sub-sample, whereby the amount of dry material for atomic absorption analysis was increased to two grams per sample.

(d) pH and conductivity. Twenty grams of the material was weighed out (fresh weight) and mixed with 20 ml of distilled water in a test tube. The slurry was allowed to sit for 30 minutes, then was mixed with a test tube vibrator, and pH and conductivity were determined immediately. Both measurements were repeated after 24 hours. These parameters were also

determined twice by independent workers.

4. Analytical procedures

(a) Digestion for atomic absorption spectrophotometry. Vegetation material was wet oxidized with concentrated nitric acid. Tailings were wet oxidized in concentrated nitric and perchloric acid. All samples were filtered with S & S Black Ribbon filter paper and brought to volume with distilled water. Water samples were analysed as prepared in the field.

(b) Neutron activation sample preparation. Approximately 0.5 g of material of tailings and vegetation was weighed into analysis capsules. Vegetation was forced into the capsules with a glass rod. The capsules were handled with plastic gloves, and sealed with a cap. One ml of water was pipetted into a capsule and then was heat sealed prior to analysis.

(c) Atomic absorption. Heavy metals Cu, Ni, Co, Pb were determined in waters and digests with a Varian AA #6 flame atomic absorption spectrophotometer with a hydrogen continuum background correction. Standard material, NBS plant material, EPA water, and standard sediment sludge CCIW was used to check digestion and analytical procedures. The results are presented in Table 17. Detection limits and error are given for the samples in Table 18.

(d) Neutron activation. The samples were irradiated at

Table 17. Control on analysis and digestion procedure

| | µg/g | Cu | Ni | Pb | Co |
|---|---|---|---|---|---|
| Standard sediment sludge C.C.I.W. | our analysis | 740 | 33.8 | 2980 | 4.3 |
| | listed values | 776 ±67 | 32.7 ±3.6 | 3100 ±200 | not given |
| Orchard leaves NBS #1571 | our analysis | 11.4 | 0.58 | 47.3 | <0.2 |
| | listed values | 12 ±1 | 1.3 ±1.2 | 45 ±3 | 0.2 not certified |

Note: Water values are given for EPA water in Table 2.

Table 18. Atomic absorption detection limits and errors.

| Element | Water | Plants | | Soil/Tailings | |
|---|---|---|---|---|---|
| (a) Detection limits (mg/l or µg/g dry weight) | | | | | |
| Cu | 0.003 | 0.12 | (0.5) | 0.25 | (1.0) |
| Ni | 0.008 | 0.2 | (0.8) | 0.4 | (1.5) |
| Co | 0.007 | 0.2 | (0.8) | 0.4 | (1.5) |
| Pb | 0.020 | 0.5 | (2.0) | 1.0 | (4.0) |
| (b) Errors estimated (± mg/l or ± µg/g dry weight) | | | | | |
| Cu | 0.006 | 0.08 | (1.25) | 0.2 | (2.5) |
| Ni | 0.006 | 0.16 | (1.6) | 0.3 | (3.0) |
| Co | 0.006 | 0.16 | (1.6) | 0.3 | (3.0) |
| Pb | 0.006 | 0.3 | (3.0) | 1.8 | (18.0) |

The values in parentheses represent the errors for those few samples with relatively small sample weight (approximately 0.200 g). Estimates are based in 0.5 mm deflection, which may be the largest contribution to the error.

at the SLOWPOKE facility, University of Toronto. Irradiation procedures are for the different materials as:

| Material | Flux $n/cm^2s$ | irradiation time | decay time | counting time | counting pos. |
|---|---|---|---|---|---|
| Water | $10^{12}$ | 6 min. | 2 min. | 5 | 1 or 4 |
| Tailings or soil | $10^{11}$ | 1 min. | 18 min. | 5 | 1 or 4 |
| Vegetation | $5 \times 10^{11}$ | 1 min. | 10 min. | 4 | 4 or 8 |

The analytical procedure was checked with N.B.S. Coal #1631 and orchard leaves SRM #1571. The results are given in Table 19.

The measurements are made with a Canberra Ge (Li) detector coupled through a 452 Ortec spectroscopy amplifier to a 8100 series, 4096 channel analyser. The entire gamma spectrum is visually inspected on the oscilloscope and integrals of significant peaks are retained with on line computer facilities. The counts are recorded on a printout, and concentrations are obtained by calibration with standards. Magnesium is corrected for the Al contributions by a 16% substraction of Al ($^{27}Al$ (n,p) $^{27}Mg$). Several samples had to be irradiated with differing irradiation schemes, due to high dead time. Water samples were transferred after irradiation to new capsules before counting.

Table 19. Standard material determined by Neutron activation analysis during U.C. sample determinations

| | | Co | U | Mg | Na | V | Al | Mn | Ca |
|---|---|---|---|---|---|---|---|---|---|
| N.B.S. Coal #1631 | our* analysis ppm | 5.6 ±0.6 | 1.66 ±0.12 | 1800 ±180 | 403 ±36 | 34.3 ±1.4 | 17100 ±170 | 41.0 ±2 | 2630 ±290 |
| | given ppm | 5.7 ±0.4 | 1.4 ±0.1 | 2000 ±500 | 414 ±20 | 35.0 ±3 | 18500 ±1300 | 40.0 ±3 | 4300 ±500 |
| Orchard leaves SRM #1571 | our* analysis ppm | 0.9 | 0.2 | 6220 ±200 | 58 ±28 | 0.55 ±0.17 | 419 ±11 | 96.8 ±2 | 13450 ±400 |
| | given ppm | 0.2* not certified | 0.029 ±0.005 | 6200 ±200 | 82 ±6 | not given | not given | 91.0 ±4 | 20900 ±300 |

*Errors are calculated as $(\sqrt{P + B}/P - B)\ 100$

Detection limits and typical errors for all elements are summarized in Table 20.

5. Bases of estimates of tailings tonnage for Lorado - Nero Lake.

Source: Griffith, J.W., (1967 p. 300; Table 49).

(a) Production data:

| | | |
|---|---|---|
| Fiscal year | 1958 - 1959 | 191,093 |
| | 1959 - 1960 | 144,393 |
| | 1957 - 1958 | 86,000* |
| | | 421,486 tons of ore |

*estimate of total

(b) Estimation data. The Lorado mine started in 1955. For approximately 10 months stockpiling of ore occurred. The rate of ore accumulation is estimated at the production rate which is given for 1957-1958, 80 to 125 tons/day. This can be translated into approximately 300 days or 30,000 tons of ore stockpiled.

In 1956 mining was supended until completion of the mill. The mill was completed in April of 1957. Assuming that ore production in 1957 proceeded at the same rate of about 100 tons/day, then for 1957 at least 160 days of mining can be expected. (Estimate 20 days/month for 8 months). This production would

Table 20. Neutron activation, detection limits and errors.

| Element | Water | Plants | Soil/Tailings |
|---|---|---|---|
| (a) Detection limits (mg/l or µg/g dry weight) | | | |
| U | 0.002 | * | * |
| Mg | 2 - 20 | 500 - 2000 | * |
| Na | * | * | * |
| V | 0.001 - 0.015 | 0.2 - 2 | * |
| Al | 0.06 - 0.4 | 25 - 100 | * |
| Mn | 0.02 - 0.4 | * | * |
| Ca | 2 - 7 | * | 300 - 2000 |
| (b) Errors typical (%) | | | |
| U | 0.3 - 10 | 0.2 - 25 | 0.1 - 16 |
| Mg | 1 - 30 | 6 - 30 | 2 - 10 |
| Na | 0.3 - 13 | 1 - 13 | 0.6 - 1 |
| V | 1 - 10 | 1 - 30 | 0.8 - 10 |
| Al | 0.7 - 20 | 1 - 30 | 1 - 2 |
| Mn | 1 - 5 | 1 - 9 | 0.5 - 5 |
| Ca | 3 - 30 | 4 - 30 | 1 - 20 |

*Indicates those instances where sample concentrations are well above detection limits. Figures represent ranges for typical detection limits; isolated instances of higher values may be obtained for unusual samples matrices.

result in an additional 16,000 tons of ore milled in 1957-1958.

The total ore milled is, therefore, the estimate of 46,000 tons, from the stockpile 1955 and production 1957.

(c) Further considerations. In 1958-1959 the mill had a daily average capacity of 524 tons/day. The mill was designed to handle initially 500 tons/day, and was then expanded to 750 tons/day. Assuming that indeed 350 tons were processed in 1957/day, the Lorado stockpile was processed within 131 days of operation of the mill in 1957. This can be expected to have happened in five months, given the difficulties of the mill. Further, because the mill started in April 1957 at the design of 500 tons/day and was increased in October 1957 to 750 tons/day, it is reasonable to assume that additional ore was milled from other shippers. Assuming better operation at 500 tons/day for 80 days in the remaining months. This results in 40,000 tons of ore from other mine operators.

The total tons of ore, therefore, estimated for 1957-1958 is 40,000 + 46,000 tons = 86,000 tons of ore processed.

It was stated by the Chief Metallurgist of Lorado Mines (Taylor, J.B. pres. comm.) that the processed ore had about a 5% sulphur content. He also stated that the tailings overflowed into Nero Lake, in the

first year of operation of the mill.

Therefore, it is concluded that at least 315,500 short tons of tailings are in Nero Lake. At most, the 86,000 tons of the first year's production are exposed at present.

6. Moss Experiment

Material. Erlenmeyer flasks were used as experimental containers. These flasks were fitted with corks through which holes had been drilled. The holes were to accommodate pipettes which were used for aeration.

Pipettes with thinned tips were prepared to control the flow of air into the flasks as fine bubbles.

(1) Treatment A

Modified BBM

10 g/400 ml dist. w. Na $NO_3$

7 g/400 ml dist. w. $KH_2$ $PO_4$

1 g/400 ml dist. w. Ca $Cl_2$ $2H_2O$

3 g/400 ml dist. w. Mg $SO_4$ $7H_2$

3 g/400 ml dist. w. $K_2HPO_4$

1 g/400 ml dist. w. No Cl

10 ml stock solution/1 medium

4.98 g/1 dist. w. Fe $SO_4$ $7H_2O$

11.42 g/1 dist. w. $H_3$ $BO_3$

0.05 ml stock solution/l medium

(2) Treatment B - tailings leachate made as follows:

5 g tailings/l dist. w. from locations

MIN-W & MS-D 5.01278 g/l
MCL-L & Control 4.89012 g/l
mixture of tailings NPT, NPR, NPG

(3) Treatment C - Nero Lake water.

(4) Treatment D - Nero Lake water & BBM.

(modified) made up to 100% BBM

- each treatment had two replicate flasks for each type of moss + 1 control flask.

- initial pH and conductivity were recorded for each treatment.

- pH was adjusted to 3.5 when necessary with 0.1 N HCl.

Addition of Mosses

- Mosses from three different locations were used. Three strands of each type of moss was added to each of the two replicate flasks for each type of treatment.

- the strands of moss were taken from lumps in the tanks. Care was taken to try to ensure that the mosses were green and healthy looking.

- Moss strands were then woven through small squares of mesh netting (to anchor the mosses and to identify individual strands). The left corner of each square was marked and the strands were designated 1, 2, 3 starting from the marked corner.

- Initial lengths were recorded for each strand of moss.

- Control flasks were left with no moss.

- Flasks were arranged on shelves with a light regime of 10.5 hours darkness and 14.5 hours light.

- Air circulation was maintained in the flasks, initially in the water then, later, just at the surface of the water to reduce disturbances to the moss.

Observations

- After a period of seven days, white mold was observed in several beakers.

- bleaching of strands of moss was also observed.

- all treatments that contained mold or bleaching were replaced with new strands.

- all mosses from MIN-W were replaced by mosses from MIN-D tank (Invasion Bay collection).

- strands that were removed were measured to determine if any growth had occurred.

- final replacement of mosses occurred on December 28th, 1980.

- moss from the control site remained free of bleaching or mold.

- clumps of mosses were placed in each of the flasks (except controls) to try to determine the cause of bleaching (i.e. whether it resulted from weaving the moss through the mesh).

- the clumps were placed in pieces of mesh netting to anchor them and then added to the flasks (experimental strands were not removed).

- pH measurements and observations as to the condition of one moss were taken daily and conductivity weekly.

- pH was adjusted to 3.5 as needed either by the addition of 0.1 N HCl or 0.1 N Na OH.

- growth in the moss clumps was observed and is measurable in number of strands after one month.

- results and observations are summarized in Figure 3.

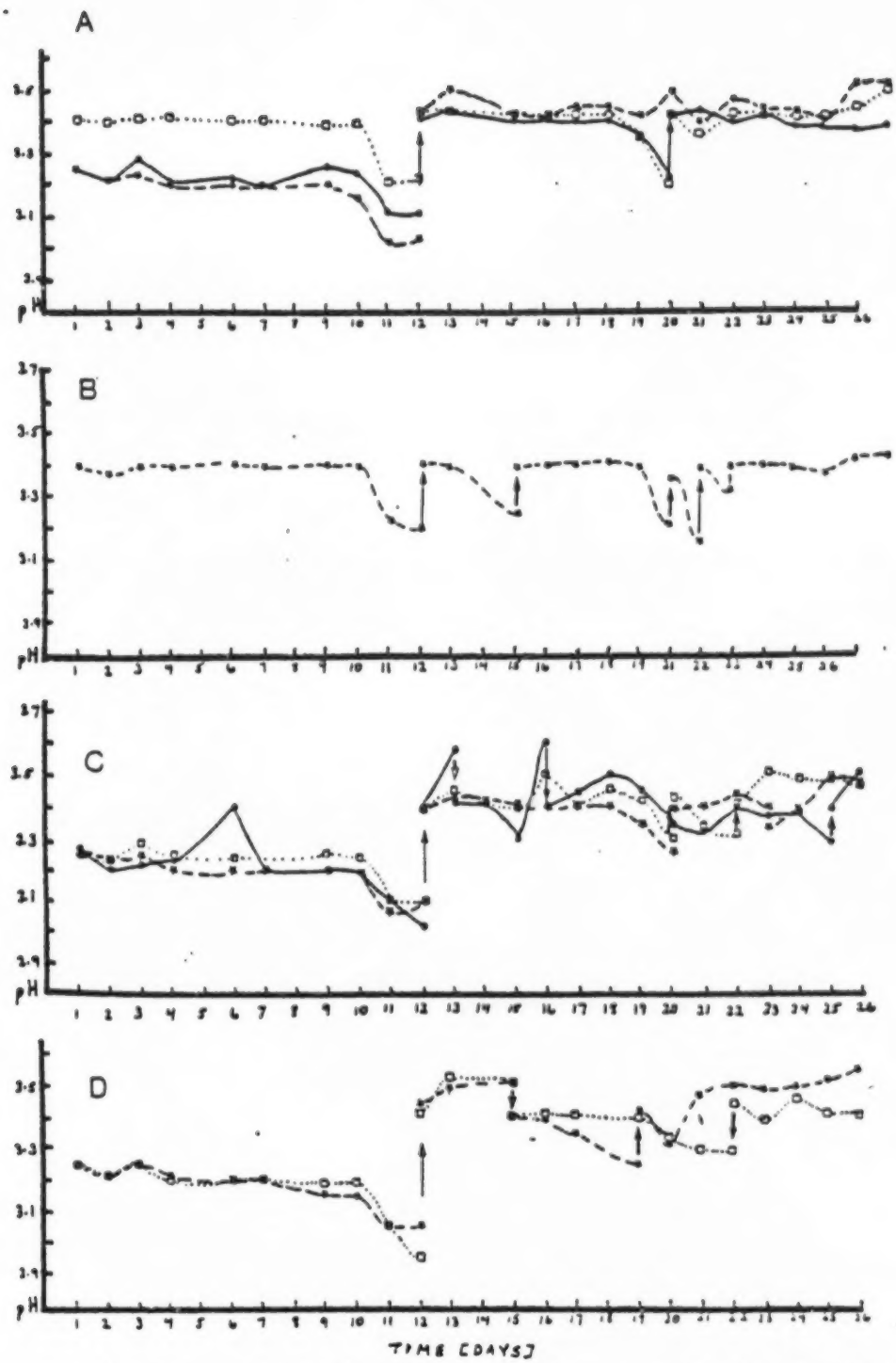


FIGURE 3: pH Monitoring Results - solutions without moss.

B, C and D treatments see legend p. 120

FIGURE 3: pH Monitoring Results

Survey strands were in 6 out of 16 flasks.

Legend

A Solutions without moss

● Nero Lake water
□ Leachate treatment
✸ Nero Lake water and 10% BBM solution

B Treatment

✸ Leachate: Control site moss, replicate 2 (MCL-L)

C Treatment

● Nero Lake Water: Control site moss, replicate 1 (MCL-L)
□ Nero Lake Water: Control site moss, replicate 2 (MCL-L)
✸ Nero Lake Water: Invasion Bay moss, replicate 1 (MIN-W); replaced with MIN-D after 10 days.

D Treatment

□ Nero Lake Water and 10% BBM solution: Control site moss, replicate 1 (MCL-L)

* Nero Lake Water and 10% BBM solution:
  Control site moss, replicate 2
  (MCL-L).

adjusted pH

| Gunnar Main Tailings | Map 2 location | Ra 226 pCi/g conc. | error | Pb 210 pCi/g conc. | error |
|---|---|---|---|---|---|
| Windblown | 1 | 53.79 | ±0.85 | 17.31 | ±0.48 |
| Bare, compacted | 3 | 308.9 | ±2.07 | 65.73 | ±1.19 |
| Bare, encrusted | 5 | 186.9 | ±1.86 | 68.34 | ±1.04 |
| Grass cover | 4 | 65.61 | ±0.58 | 14.12 | ±0.45 |
| | # of samples | | (s.d.)* | | (s.d.)* |
| Mean concentration: | 4 | 138 | ±136 | 41 | ±29 |
| Elliot Lake | | | | | |
| Bare tailings | 6 | 88 | ±103 | 50 | ±49 |
| Tailings with *T. latifolia* | 6 | 49 | ± 37 | 97 | ±54 |
| Bancroft | | | | | |
| Bare tailings | 6 | 55 | ±70 | 139 | ±147 |
| Tailings with *T. latifolia* | 6 | 86 | ±70 | 60 | ± 63 |
| Lorado | Map 1 location | | error | | error |
| Dry tailings | 1 | 26.66 | ±0.65 | 7.06 | ±0.37 |

Ruggles et al. (1979)

| Nero Lake | Sample site | | | | |
|---|---|---|---|---|---|
| Sediments | 3 | 150.3 | n.g.* | 190 | n.g.* |
| Sediments | 1 | 229.3 | n.g. | 391 | n.g. |

* n.g.: not given - s.d.: standard deviation

Some Preliminary Comments:

The concentrations of Ra 226 and Pb 210 in the Gunnar tailings appear slightly larger than in Elliot Lake or Bancroft. The sample size (n = 4) is very small and the variance is large. More samples need to be analysed for radionuclides to confirm the observed concentration ranges. The one sample from the dry exposed Lorado tailings is much lower than the concentrations of Ra 226 and Pb 210 reported for tailings or sediments in Nero Lake. Further analysis is required.

Radionuclides in grasses:

Absolute concentrations:

*Hodeum jubatum* (Map 2; Site S2)

| | Ra 226 pCi/g | Pb 210 pCi/g |
|---|---|---|
| Tailings | 329.6 ±1.53 | 67.43 ±1.03 |
| Roots | 44.8 ±2.14 | 159.0 ±1.99 |
| Stems and leaves | 14.1 ±0.84 | 16.18 ±0.70 |
| Seeds | 0.7 ±0.32 | 0.46 ±0.28 |

*Calamagrostis inexpansa* (Map 2; Site C)

| | | |
|---|---|---|
| Tailings | 96.09 ±0.99 | 25.15 ±0.71 |
| Roots | 4.45 ±0.85 | 21.75 ±0.62 |
| Stems and leaves | 1.65 ±0.57 | 4.47 ±0.44 |
| Seeds | 2.96 ±0.46 | 2.28 ±0.36 |

Concentration factor in aerial parts: (Stems, leaves & seeds/tailings).

| | *H. jubatum* | *C. inexpansa* |
|---|---|---|
| Ra 226 | 0.043 | 0.047 |
| Pb 210 | 0.25 | 0.27 |

Transported fraction from tailings to roots: (roots/tailings).

| | *H. jubatum* | *C. inexpansa* |
|---|---|---|
| Ra 226 | 0.13 | 0.045 |
| Pb 210 | 2.35 | 0.86 |

Transported fraction from roots to aerial parts:
(stems, leaver & seeds/roots).

| | *H. jubatum* | *C. inexpansa* |
|---|---|---|
| Ra 226 | 0.33 | 1.03 |
| Pb 210 | 0.1 | 0.3 |

Some Preliminary Comments:

The absolute concentrations of Ra 226 and Pb 210 in the grasses *Hordeum jubatum, Calamagrostis inexpansa* differ considerably.

Concentration factors indicate, that the proportions between the plant parts are the same for both species. Differences exist between Pb 210 and Ra 226, which are not unexpected. Drastically differing are the factors for Pb 210 from the tailings to the roots between the species. In *C. inexpansa* more radium appears to be transported to the aerial parts of the plant than in *H. jubatum*. Further analysis is needed.

Radionuclids in Leptodictyum riparium (Map 2; Site M

This report:

| | Ra 226 pCi/g (dry weight) | error | Pb 210 pCi/g (dry weight) | error |
|---|---|---|---|---|
| Moss | 8.16 | ±1.50 (48) | 90.94 | ±1.17 (540) |
| Moss substrate | 4.97 | ±0.98 | 14.92 | ±0.67 |

| | pCi/g (ash weight) | | pCi/g (ash weight) | |
|---|---|---|---|---|
| Ruggles et al (1979): | | | | |
| Moss station 5 | 14 | n.g.* | 1950 | n.g.* |
| Moss station 6 | 33 | n.g. | 1150 | n.g. |

*not given

The estimated dry weight/ash weight factor based on data by Ruggles et al (1979) p. 43 is six and the adjusted concentration for L. riparium from this report are given in brackets. Clearly comparing the concentrations large variations are indicated. In order to determine the uptake factors, more samples (moss - moss substrate) are required.

The periphytic detrital aggregate in Beaverlodge Bay had 7.19 pCi/g Ra 226 and 20.9 pCi/g with an error of ±1.00. Assuming that stations 9, 10 and 11 of Ruggles et al (1979) consist of similar material, again these results add to the variation. Clarification is being sought with further analysis of samples collected during this survey.

POOR

QUALITY

ORIGINAL